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# Energy from the West: Energy Resource Development Systems Report
## Volume IV: Uranium

Oklahoma Univ, Norman Science and Public Policy Program

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# Energy from the West

## Energy Resource Development Systems Report Volume IV: Uranium

## Interagency Energy/Environment R&D Program Report

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## Volume IV: Uranium

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Energy
from
the
West

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# FORWARD

The production of electricity and fossil fuels inevitably impacts Man and his environment. The nature of these impacts must be thoroughly understood if balanced judgements concerning future energy development in the United States are to be made. The Office of Energy, Minerals and Industry (OEMI), in its role as coordinator of the Federal Energy/Environment Research and Development Program, is responsible for producing the information on health and ecological effects - and methods for mitigating the adverse effects - that is critical to developing the Nation's environmental and energy policy. OEMI's Integrated Assessment Program combines the results of research projects within the Energy/Environment Program with research on the socioeconomic and political/institutional aspects of energy development, and conducts policy - oriented studies to identify the tradeoffs among alternative energy technologies, development patterns, and impact mitigation measures.

The Integrated Assessment Program has supported several "technology assessments" in fulfilling its mission. Assessments have been supported which explore the impact of future energy development on both a nationwide and a regional scale. Current assessments include national assessments of future development of the electric utility industry and of advanced coal technologies (such as fluidized bed combustion). Also, the Program is conducting assessments concerned with multiple-resource development in two "energy resource areas":

- Western coal states
- Lower Ohio River Basin

This report, which describes the technologies likely to be used for developing six energy resources in eight western states, is one of three major reports produced by the "Technology Assessment of Western Energy Resource Development" study. (The other two reports are an impact analysis report and a policy analysis report.) The report is divided into six volumes. The first volume describes the study, the organization of this report and briefly outlines laws and regulations which affect the development of more than one of the six resources considered in the study. The remaining five volumes are resource specific and describe the resource base, the technological activities such as exploration, extraction and conversion for developing the resource, and resource specific laws and regulations. This report is both a compendium of information and a planning handbook. The descriptions of the various energy development technologies and the extensive compilations of technical baseline information are written to be easily understood by laypersons. Both professional planners and interested citizens should find it quite easy to use the information presented in this report to make general but useful comparisons of energy technologies and energy development alternatives, especially when this report is used in conjunction with the impact and policy analysis reports mentioned above.

Your review and comments on these reports are welcome. Such comments will help us to improve the usefulness of the products produced by our Integrated Assessment Program.

Steven R. Reznek

Acting Deputy Assistant Administrator
for Energy, Minerals and Industry

# PREFACE

This Energy Resource Development System (ERDS) report has been prepared as part of "A Technology Assessment of Western Energy Resource Development" being conducted by an interdisciplinary research team from the Science and Public Policy Program (S&PP) of the University of Oklahoma for the Office of Energy, Minerals and Industry (OEMI), Office of Research and Development, U.S. Environmental Protection Agency (EPA). This study is one of several conducted under the Integrated Assessment Program established by OEMI in 1975. Recommended by an interagency task force, the purpose of the Program is to identify economically, environmentally, and socially acceptable energy development alternatives. The overall purposes of this particular study were to identify and analyze a broad range of consequences of energy resource development in the western U.S. and to evaluate and compare alternative courses of action for dealing with the problems and issues either raised or likely to be raised by development of these resources.

The Project Director was Irvin L.(Jack) White, Assistant Director of S&PP and Professor of Political Science at the University of Oklahoma. White is now Special Assistant to Dr. Stephen J. Gage, EPA's Assistant Administrator for Research and Development. R. Leon Leonard, now a senior scientist with Radian Corporation in Austin, Texas, was a Co-Director of the research team, Associate Professor of Aeronautical, Mechanical, and Nuclear Engineering and a Research Fellow in S&PP at the University of Oklahoma. Leonard was responsible for editing and managing the production of this report. EPA Project Officer was Steven E. Plotkin, Office of Energy, Minerals and Industry, Office of Research and Development. Plotkin is now with the Office of Technology Assessment. Other S&PP team members are: Michael A. Chartock, Assistant Professor of Zoology and Research Fellow in S&PP and the other Co-Director of the team; Steven C. Ballard, Assistant Professor of Political Science and Research Fellow in S&PP; Edward J. Malecki, Assistant Professor of Geography and Research Fellow in S&PP; Edward B. Rappaport, Visiting Assistant Professor of Economics and Research Fellow in S&PP; Frank J. Calzonetti, Research Associate (Geography) in S&PP; Timothy A. Hall, Research Associate (Political Science); Gary D. Miller, Graduate Research Assistant (Civil Engineering and Environmental Sciences); and Mark S. Eckert, Graduate Research Assistant (Geography).

Chapters 3-7 were prepared by the Radian Corporation, Austin, Texas, under subcontract to the University of Oklahoma. In each of these chapters, Radian is primarily responsible for the description of the resource base and the technologies and S&PP is primarily responsible for the description of laws and regulations. The Program Manager at Radian was C. Patrick Bartosh. Clinton E. Burklin was responsible for preparation of these five chapters. Other contributors at Radian were: William R. Hearn, Gary D. Jones, William J. Moltz, and Patrick J. Murin.

Additional assistance in the preparation of the ERDS report was provided by Martha W. Gilliland, Executive Director, Energy Policies Studies, Inc., El Paso, Texas; Rodney K. Freed, Attorney, Shawnee, Oklahoma; and Robert W. Rycroft, Assistant Professor of Political Science, University of Denver, Denver, Colorado.

# ABSTRACT

This report describes the technologies likely to be used for development of coal, oil shale, uranium, oil, natural gas, and geothermal resources in eight western states (Arizona, Colorado, Montana, New Mexico, North Dakota, South Dakota, Utah, and Wyoming). It is part of a three-year "Technology Assessment of Western Energy Resource Development." The study examines the development of these energy resources in the eight states from the present to the year 2000. Other reports describe the analytic structure and conduct of the study, the impacts likely to result when these resources are developed, and analyze policy problems and issues likely to result from that development. The report is published in six volumes. Volume 1 describes the study, the technological activities such as exploration, extraction, and conversion for developing the resource, and laws and regulations which affect the development of more than one of the six resources considered in the study. The remaining five volumes are resource specific: Volume 2, Coal; Volume 3, Oil Shale; Volume 4, Uranium; Volume 5, Oil and Natural Gas; and Volume 6, Geothermal. Each of these volumes provides information on input materials and labor requirements, outputs, residuals, energy requirements, economic costs, and resource specific state and federal laws and regulations.

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## CONVERSION FACTORS
## ENGLISH UNITS/METRIC UNITS

| To Convert From | To | Multiply By |
|---|---|---|
| acre | $m^2$ | 4046.9 |
| acre-ft/year | gpm | 0.6200 |
| acre-ft/year | $m^3$/yr | 1233.5 |
| Btu | joules | 1054.4 |
| Btu/hr | watts | 0.2931 |
| ft | m | 0.3048 |
| gpm | $m^3$/min | 0.003785 |
| hp | watts | 745.7 |
| lb | kg | 0.4536 |
| psi | pascal | 6894.8 |
| ton | kg | 907.18 |

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## VOLUME IV

## CHAPTER 5

# THE URANIUM RESOURCE DEVELOPMENT SYSTEM

## 5.1 INTRODUCTION

### 5.1.1 Background

This document is one of several reports issued in support of a "Technology Assessment of Western Energy Resource Development," a project jointly conducted by the Science and Public Policy Program of the University of Oklahoma and the Radian Corporation of Austin, Texas. The project is funded by the Office of Energy, Minerals, and Industry, Office of Research and Development, Environmental Protection Agency under Contract 68-01-1916. This document is issued as Chapter 5 of the "Energy Resource Development System" (ERDS) report. For each of six energy resources, the ERDS report describes the energy resource base, the technologies used to develop the resource, the inputs and outputs for each development technology, and the laws and regulations applying to the deployment and operation of each technology. Resources described in the ERDS report are: coal, oil shale, uranium, oil, natural gas, and geothermal energy.

This chapter describes the technologies, inputs, outputs, laws, and regulations associated with the development of uranium resources. The chapter comprises five major sections which begin with a general description of the uranium resource. The remaining sections describe the steps or activities involved in developing uranium resources.

Section 5.2, Uranium Resources, describes the characteristics of the uranium resource and gives estimates of the quality and quantity of the known and projected uranium reserves. This section also discusses the uranium resource in terms of location and ownership.

The remaining sections describe the development of the uranium resource as a basic sequence of activities. In the development of the uranium resource, these activities include exploration, mining, and milling. For each activity, "technological alternatives" are discussed which represent potential development options, (e.g., uranium can be mined on the surface, underground, or extracted in-situ. When available, input requirements and outputs for each technological alternative or activity are presented. Input requirements discussed in this report include: manpower, materials and equipment, economics, water, land, and ancillary energy. The outputs include the residuals that may pose environmental hazards such as: air emissions, water effluents, solid wastes, noise pollution, occupational health and safety hazards, and odors.

Section 5.3 discusses the technologies, inputs and outputs, laws and regulations associated with uranium exploration. Section 5.4 discusses the same items for the mining of uranium including discussions of underground mining, surface mining, and in-situ solutional mining. Section 5.5 describes uranium milling to form the intermediate product, "yellowcake".

### 5.1.2 Summary

Tables 5-1 through 5-5 summarize the input requirements and outputs associated with development of the uranium resources.

## TABLE 5-1. SUMMARY OF IMPACTS ASSOCIATED WITH THE EXPLORATION FOR A 1200 TON/DAY URANIUM MINE

| | |
|---|---|
| Inputs | |
| Manpower | 400 man-years |
| Materials and Equipment | |
| • drilling rigs | 4 to 6 |
| • heavy duty vehicles | 15 |
| Economics[1] | $804,000 |
| Water (over life of exploration effort) | 2.4 acre-ft (2.96 $km^3$) |
| Land | 50 acres (202 $km^2$) |
| Ancillary Energy | 8.34 x $10^9$ Btu/yr (8.8 TJ/yr) |
| Outputs | |
| Air Emissions | Minimal |
| Water Effluents | Minimal |
| Solid Wastes | Minimal |
| Noise Pollution | $\leq$65dBA @1000 ft. |
| Occupational Health and Safety | Minimal |

[1] As 1977 dollars, adjusted from reported 1976 dollars.

## TABLE 5-2. SUMMARY OF IMPACTS ASSOCIATED WITH A 1200 TON/DAY OPEN PIT URANIUM MINE

| | |
|---|---|
| **Inputs** | |
| Manpower | |
| • construction | 276 man-years |
| • operating | 178 men |
| Materials and Equipment | |
| • structural steel, piping, tubular goods | 400 tons (360 Mg) |
| • concrete | 10 tons (9 Mg) |
| • refined products | 5100 tons (4600 Mg) |
| • heavy duty vehicles | 74 items |
| Economics | |
| • capital investment[1] | $21.2 million |
| • operating cost[1] | $ 7.3 million/yr |
| Water | |
| • externally supplied | 1.1 acre-ft/year (1.4 $km^3$/yr) |
| • internal recycle | ∿44 acre-ft/year (54 $km^3$/yr) |
| Land | 1800 acres (7.3 $Mm^2$) |
| Ancillary Energy | |
| • electricity | 6.9 x $10^6$ kwh/yr (24 TJ/yr) |
| • fuels | 1.3 x $10^6$ gallons/yr (4.9 $km^3$/yr) |
| **Outputs** | |
| Air Emissions | |
| • particulates | 1580 tons/yr (1400 Mg/yr) |
| • sulfur oxides | 39 tons/yr (35 Mg/yr) |
| • carbon monoxide | 409 tons/yr (370 Mg/yr) |
| • nitrogen oxides | 539 tons/yr (490 Mg/yr) |
| • carbon dioxide | 617 tons/yr (560 Mg/yr) |
| • Rn-222 gas | 33 curies/yr |
| Water Effluents | 500-1500 acre-ft/yr (616-1850 $km^3$/yr) |
| Solid Water | Returned to mine |
| Noise Pollution | 88 dBA @50 ft. |
| Occupational Health and Safety | |
| • deaths | 1.8 deaths/yr |
| • injuries | ≤69 injuries/yr |
| • lost time | 4280 man-days/yr |

---

[1] 1977 dollars

## TABLE 5-3. SUMMARY OF IMPACTS ASSOCIATED WITH A 1200 TON/DAY UNDERGROUND URANIUM MINE

| | |
|---|---|
| **Inputs** | |
| Manpower | |
| • construction | 122 man-years |
| • operating | 197 men |
| Materials and Equipment | |
| • concrete | 27,000 tons (24,000 Mg) |
| • pipe and tubing | 1,350 tons (1200 Mg) |
| • structural steel | 1,750 tons (1600 Mg) |
| • reinforcing bars | 2,000 tons (1800 Mg) |
| • continuous miners | 4 items |
| Economics | |
| • capital investment[1] | $ 30 million |
| • annual operating cost[1] | $ 13 million |
| Water (potable) | 17.9 acre-ft/yr (22 $km^3$/yr) |
| Land | 8 acres (32 $km^2$) |
| Ancillary Energy | |
| • electricity | 24.5 x $10^6$ kwh/yr (88 TJ/yr) |
| • fuel for mine heating | 11 x $10^6$ Btu/yr (12 GJ/yr) |
| • equipment fuels | 120 x $10^3$ gal/yr (450 $m^3$/yr) |
| **Outputs** | |
| Air Emissions | |
| • Rn-222 gas | 1073 curies/yr |
| • particulates | 0.7 tons/yr (0.6 Mg/yr) |
| • sulfur oxides | 1.6 tons/yr (1.5 Mg/yr) |
| • carbon monoxide | 13.3 tons/yr (12.1 Mg/yr) |
| • hydrocarbons | 2.2 tons/yr (2.0 Mg/yr) |
| • nitrogen oxides | 21.9 tons/yr (20.0 Mg/yr) |
| • aldehydes | 0.2 tons/yr (0.2 Mg/yr) |
| • organic acids | 0.2 tons/yr (0.2 Mg/yr) |
| • carbon dioxide | 1314 tons/yr (1200 Mg/yr) |
| Water Effluents | 4839 acre ft/yr (6.0 $Mm^3$/yr) |
| Solid Wastes | negligible |
| Noise Pollution | $\leq$65 dBA @500 ft |
| Occupational Health and Safety | |
| • deaths | 1 death/year |
| • injuries | 25 injuries/year |

---

[1] As 1977 dollars, adjusted from reported 1975 dollars.

## TABLE 5-4. SUMMARY OF IMPACTS ASSOCIATED WITH A 250 TONS OF YELLOW CAKE/YEAR IN-SITU SOLUTION MINE

| | |
|---|---|
| Inputs | |
| Manpower | |
| • construction | 60 man-years |
| • operation | 75 men |
| Materials and Equipment | |
| • well cement | unavailable |
| • piping | unavailable |
| • chemicals | 3000 ton/yr (2700 Mg/yr) |
| Economics | |
| • capital investment[1] | $23.4 million |
| • annual operating cost[1] | $12.5 million |
| Water | 0.6 acre-ft/yr (.7 km$^3$/yr) |
| Land | |
| • mining activities | 25-100 acres/yr (101-405 km$^2$/yr) |
| • milling activities | 5 acres (20 km$^2$) |
| Ancillary Energy | |
| • electricity | 26.3 x $10^6$ kwh/yr (95 TJ/yr) |
| • propane fuel | 3.7-11 x $10^9$ Btu/yr (4-12 GJ/yr) |
| • drilling rig fuel | 320,000 gal/yr (1.2 km$^3$/yr) |
| Outputs | |
| Air Emissions | |
| • $NH_3$ | 30 ton/yr (27 Mg/yr) |
| • $CO_2$ | 0.5-1 x $10^3$ ton/yr (450-907 Mg/yr) |
| • $NH_4Cl$ | 95 ton/yr (86 Mg/yr) |
| • $U_3O_8$ | 0-0.5 ton/yr (0-0.5 Mg/yr) |
| Water Effluents (amt not evaporated) | 3 acre-ft/yr (4 km$^3$/yr) |
| Solid Wastes | <1600 ton/yr (1500 Mg/yr) |
| Noise Pollution (intermittent) | <65 dBA @1000 ft |
| Occupational Health and Safety | unavailable |

---

[1] 1977 dollars

TABLE 5-5. SUMMARY OF IMPACTS ASSOCIATED WITH A 1200 TON/DAY URANIUM MILL

| | |
|---|---|
| Inputs | |
| Manpower | |
| • construction | 300 man-years |
| • operation | 77 men |
| Materials and Equipment | |
| • concrete | 6,000 tons (5400 Mg) |
| • piping and structural steel | 400 tons (360 Mg) |
| • pumps and motors | 35 tons (32 Mg) |
| • chemicals | 13,000 ton/yr (12,000 Mg/yr) |
| • heavy duty vehicles | 6 items |
| Economics | |
| • investment capital[1] | \$11.9 million |
| • annual operating cost[1] | \$ 4.7 million |
| Water | 300 acre-ft/yr (0.4 Mm$^3$/yr) |
| Land | 300 acres (1.2 Mm$^2$) |
| Ancillary Energy | |
| • electricity | 7.7 x $10^6$ kwh/yr (28 TJ/yr) |
| • heating fuel | 171 x $10^9$ Btu/yr (180 TJ/yr) |
| Outputs | |
| Air Emissions | |
| • $SO_2$ | 4.5 ton/yr (4.1 Mg/yr) |
| • $Cl_2$ | 0.1 ton/yr (0.1 Mg/yr) |
| • hydrocarbons | 0.2 ton/yr (0.2 Mg/yr) |
| • $CO_2$ | 526 ton/yr (477 Mg/yr) |
| • $NO_x$ | 1.3 ton/yr (1.2 Mg/yr) |
| • Rn-222 gas | 11,000 curies/yr |
| • particulates | 175 ton/yr (160 Mg/yr) |
| Water Effluents | none[2] |
| Solid Wastes (landfilled) | 438,000 ton/yr (400 Tg/yr) |
| Noise Pollution | 75 dBA @100 ft |
| Occupational Health and Safety | |
| • deaths | 0.046 deaths/yr |
| • injuries | 14.1 injuries/yr |
| • lost time | 873 days/yr |

---

[1] 1977 dollars

[2] 600 acre-ft/yr are evaporated from evaporation ponds.

## 5.2 URANIUM RESOURCES

### 5.2.1 History of Nuclear Energy

Commercial use of nuclear fission as an energy source has a history of only 20 years; the first electric power generation plant went into operation at Shippingport, Pennsylvania in 1957. The use of nuclear power as an energy source grew out of nuclear weapons development during World War II. With the creation of the Atomic Energy Commission (AEC) following the war the government began an explicit effort to fund and develop the commercial use of nuclear energy. The major rationale behind this development has been the assumption of a large supply of nuclear resources that could one day be substituted for the more limited fossil fuel sources. The AEC was disbanded in 1974 and its responsibilities divided between two government agencies. Today, the development of nuclear energy is overseen by the U.S. Department of Energy. The responsibility of regulating the use of nuclear energy has been assumed by the Nuclear Regulatory Commission (NRC).

The development of nuclear fission as an energy source has been strongly influenced by the complex technologies and the hazards from radioactivity. The complexity of the technologies has required continuous research and development, and as a result, development costs have been higher than the private sector has been willing to bear. Together with the need for regulating safe and peaceful use of radioactive materials, the level of cost has resulted in a major role for the federal government in the development of nuclear energy.

### 5.2.2 Basics of Nuclear Energy

Nuclear fission is the process whereby certain heavy atoms split into two dissimilar atoms and, in doing so, release energy, one or several neutrons, and other sub-atomic particles. The neutrons can then react with other atoms, causing them to fission, and thus create a "chain reaction." The term "nuclear criticality" is used to describe a sustaining chain reaction; that is, the chain reaction will continue until conditions are altered to make the reaction cease. In a nuclear reactor, the controlled chain reaction creates heat, which can be converted to electrical energy.

Three isotopes[1] fission readily and are usually referred to as fissile[2] fuels: U-235, Pu-239 (plutonium-239) and U-233. When an atom fissions, the two newly formed atoms are called fission products or fission fragments. Since the splitting can occur in a variety of different ways, various fission products are formed; for example, strontium, cesium, iodine, krypton, xenon, etc. The nuclear fuels and most of these fission products are radioactive, thereby creating fuel and fuel by-product handling problems that are unique to the nuclear power industry.

Radioactivity (or "radioactive decay") can be described as the spontaneous transformation of an atom into either a new atom or a different isotope of the original atom with the concurrent release of energy in the form of highly energetic alpha particles, beta particles, or gamma rays. The term "half-life" indicates how rapidly a material will decay. In the time equal to a half-life, the amount of radioactive material decreases by one-half. In addition to a number of beneficial uses (including several in medicine), these particles and rays can have significant adverse effects on the cells of biological organisms. The effect of radioactivity on biological organisms is determined by the rate of decay and by the type of particles and rays that are released. Two units for describing radioactivity that will be used throughout this chapter are "curies" and "rems." A curie is a measure of the number of unstable nuclei that are undergoing transformation in the process of radioactive decay. One curie equals the disintegration of $3.7 \times 10^{10}$ nuclei per second. A rem is a unit to measure the radiation received by organisms in the form of the particles and rays.[1] The natural background dose, not including medical x-rays, is approximately $125 \times 10^{-3}$ rem.[2] In many cases the notation "mrem" (or millirem) will be used, where one millirem equals $10^{-3}$ rem. Thus, natural background dose levels may be expressed as 125 mrem.

---

[1] Isotopes are a grouping of atoms that contain the same number of protons but a different number of neutrons. Two or more isotopes of an element exhibit similar chemical properties but different physical properties because of their different atomic weight. For example, natural uranium has three isotopes, Uranium-234, Uranium-235, and Uranium-238. All contain 92 protons but a different number of neutrons.

[2] Fissile is a term that describes nuclear fuels that will fission when bombarded with low-energy neutrons. Fertile is a term that describes a material which can be converted into fissile nuclear fuels.

Two generations of nuclear fission technology are either available or under development: conventional fission reactors and breeder reactors. Conventional fission reactors are commercially available and represented approximately 10 percent of the nation's electrical generating capacity in 1977.[1] These reactors are expected to be the major source of nuclear-generated electric power for the next 20 years. Two types of conventional fission reactors are presently available in the U.S.: the pressurized water reactor (PWR) and the boiling water reactor (BWR). As of December 1976 these reactors were producing 45,451 megawatts of electricity.[2] The Federal Energy Administration expects conventional fission reactors to have 1420 gigawatts capacity by 1985.[3] Three factors should be noted with regard to conventional fission reactors:

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[1] The conversion from curies to rems for a certain type of radiation can be made when the biological damage caused by that radiation is known. The received dose in rem units is determined by the curie value and the extent of biolobical damage.

[2] Nuclear Regulatory Commission. Operation of Bear Creek Project, Rocky Mountain Energy Company, Docket No. 40-8452. Washington, D.C.: Nuclear Regulatory Commission, Office of Nuclear Materials Safety and Safeguards. June 1977. p. H-3.

1) Although they are commercially available, engineering problems are still being solved.

2) The rate at which these reactors have been brought into operation has been slower than projected. This has been due to economic factors and the delays in the licensing process caused by various regulatory agencies.

3) A controversy exists over the amount of uranium that is available for conventional reactor use.

The last factor, the amount of economically available sources of uranium, has prompted the development of the liquid metal fast breeder reactor (LMFBR). The breeder reactor is attractive because it produces plutonium, which may be used to fuel other LMFBR's and therefore reduces the amount of uranium required per reactor per year. ERDA is presently carrying on a development program for the LMFBR. The future of this technology is uncertain due to the present administration's hesitance to develop the breeder reactor.

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[1] Allen, L.R., Manager, N.S.S. Marketing. Babcock & Wilcox Co., NPGD, Lynchburg, VA. Information from telephone conversation. December 19, 1977.

[2] Mygatt, Peter. "Status of Nuclear Generating Units in the United States as of December 31, 1976." ERDA News Release No 77-19. Grand Junction, Colorado: U.S. Energy Research and Development Administration, Grand Junction Office. March 1, 1977.

[3] Nuclear Regulatory Commission. Operation of Bear Creek Project, Rocky Mountain Energy Company, Docket No. 40-8452. Washington, D.C.: Nuclear Regulatory Commission, Office of Nuclear Materials Safety and Safeguards. June 1977. p. H-3.

### 5.2.3 Characteristics of the Resource

Uranium is one of the elements and occurs in nature as a compound. About 95 percent of the uranium mined in the U.S. exists as uranium oxide (known as uraninite or pitchblende). Most of the remaining five percent exists in uranium hydrous silicate compounds (known as coffinite) or potassium uranium vandate (known as carnotite).[1] Uranium consists of three naturally occurring isotopes in the following proportions: 99.29 percent U-238, 0.71 percent U-235, and a trace of U-234. A ton[2] of uranium-bearing ore contains, on the average, four to five pounds of uranium oxide from which 0.024 to 0.030 pound of U-235 can be obtained.

Most of the uranium mined in the U.S. is found in three types of deposits: ancient conglomerates, petrified rivers, and veins. Ancient conglomerates are old stream channel deposits that were formed more than one-half million years ago.[3] Petrified rivers and veins are both sandstone formations. The difference between the two is that the host sandstone containing the uranium lies horizontally in the first and vertically in the second. These sandstone formations provide 95 percent of the ore mined in the U.S. The distribution of deposits of "low cost" ($10.00 per pound $U_3O_8$) ore reserves with depth are shown in Figure 5-1.

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[1] Singleton, Arthur L. (1968) Sources of Nuclear Fuel. AEC Understanding the Atoms Series. Washington: GPO. p. 11.

[2] Unless preceded by "metric", "ton" will refer to a short ton (2,000 pounds). A metric ton is 1000 Kilograms (2,205 pounds).

[3] Singleton, Arthur L., *op.cit.*, p. 22.

### 5.2.4 Quantity of the Resource

Uranium resources and reserves are normally discussed in terms of quantities available at four cost of recovery levels: $10, $15, $30, and $50 per pound of $U_3O_8$. The Energy Resource and Development Administration (ERDA) estimates that the United States uranium reserves, as of January 1, 1977 were 410,000 tons of uranium oxide ($U_3O_8$) contained in 305 million tons of ore with an average grade of about 0.14 percent $U_3O_8$, recoverable at a cost of $15 or less per pound.[1,2] These estimates compare with estimates last year of 430,000 tons of $U_3O_8$. The reduction does not indicate a decrease in the amount of uranium ore present in the ground but does indicate that this amount of uranium is no longer in the $15 cost category.

Additions to $15 reserves in 1976 contained an estimated 48,000 tons of $U_3O_8$.[3] However, during the year about 14,000 tons of $U_3O_8$ were mined and shipped to mills, and 54,000 tons were subtracted from the $15 reserve category, primarily due to

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[1] Estimates are made by evaluating original drilling and other data furnished by the uranium mining industry of ERDA's Grand Junction, Colorado, Office. Estimated operating and forward capital costs were used by ERDA in calculating reserves. Profit and "sunk" costs, such as expenditures for property acquisition, exploration, and mine development, are not included. Therefore, the figure of $15 per pound does not represent the price at which the estimated reserve would be sold.

[2] ERDA. Statistical Data of the Uranium Industry. Grand Junction, Colorado: U.S. Energy Research and Development Administration, Grand Junction Office. January 1, 1977. p. 55.

[3] *Ibid.*, p. 21.

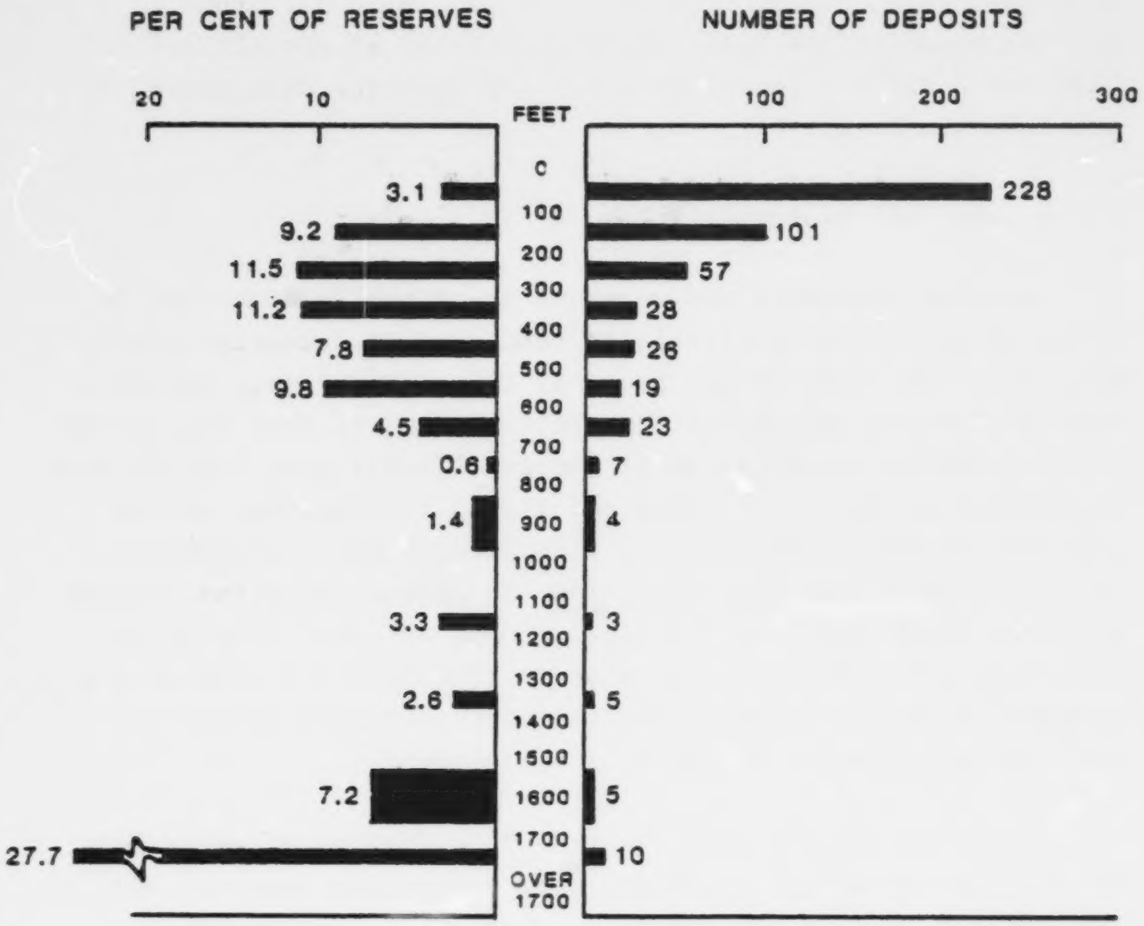

Figure 5-1. Distribution of 1/1/77 Ore Reserves by Depth of Ore - $10.00 Reserves.

Source: ERDA. Statistical Data of the Uranium Industry. Grand Junction, Colorado: U.S. Energy Research and Development Administration, Grand Junction Office, January 1, 1977. p. 50.

inflation, and added to higher cost reserves.[1] A history of past reserve estimates and production is shown in Table 5-6. Table 5-7 gives ERDA's estimates of uranium reserves at each of these price levels as of January 1, 1977.

Due to the escalation in mining and milling costs, and increasing uranium prices, ERDA has dropped the $8 per pound classification and data on reserves at a cost of $10 per pound $U_3O_8$ are the lowest cost level reported. The prices include the cost of exploration, mining, and milling.

The potential resources (that amount estimated to be ultimately recoverable at the given price level) are shown in Table 5-8. Data for uranium are unique in that reserve estimates are provided for various prices. For other energy resources, "reserves" are identified resources which are economically recoverable, and no specific price is given. These differences in data presentation make reserve comparisons between uranium and other resources difficult.

During 1974, ERDA greatly expanded the scope of its program to assess potential uranium resources and implemented plans to investigate all parts of the U.S., including Alaska, and to evaluate geologic formations not previously considered. This is known as the National Uranium Resource Evaluation (NURE) program. For the NURE program, the single class of potential uranium resources was expanded to three classes. The three classes of potential resources are arranged in order of decreasing reliability from top to bottom. "Probable" potential is in existing mining districts and productive formations; "possible" potential is in productive provinces and productive formations;

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[1] ERDA. Statistical Data of the Uranium Industry. Grand Junction, Colorado: U.S. Energy Research and Development Administration, Grand Junction Office. January 1, 1977. p. 21.

## TABLE 5-6. URANIUM ORE RESERVES AND PRODUCTION, 1947 THROUGH 1976

| Year End | Tons $U_3O_8$ In Ore<br>Shipment to Mills[a] | Cum. Prod. | Reserve Estimation[b] | | | Sum of Reserves and Cum. Prod. | | |
|---|---|---|---|---|---|---|---|---|
| | | | ($8) | ($15) | ($30) | ($8) | ($15) | ($30) |
| 1947 | - | - | 2,200 | | | 2,200 | | |
| 1948 | 100 | 100 | 2,200 | | | 2,300 | | |
| 1949 | 500 | 600 | 2,200 | | | 2,800 | | |
| 1950 | 800 | 1,400 | 3,000 | | | 4,400 | | |
| 1951 | 1,100 | 2,500 | 5,800 | | | 8,300 | | |
| 1952 | 1,300 | 3,800 | 7,300 | | | 11,100 | | |
| 1953 | 2,300 | 6,100 | 15,200 | | | 21,300 | | |
| 1954 | 3,500 | 9,600 | 27,600 | | | 37,200 | | |
| 1955 | 4,400 | 14,000 | 67,600 | | | 81,600 | | |
| 1956 | 8,400 | 22,400 | 120,200 | | | 142,600 | | |
| 1957 | 9,800 | 32,200 | 166,300 | | | 198,500 | | |
| 1958 | 14,000 | 46,200 | 181,800 | | | 228,000 | | |
| 1959 | 17,400 | 63,600 | 197,100 | | | 260,700 | | |
| 1960 | 18,800 | 82,400 | 187,100 | | | 269,500 | | |
| 1961 | 18,500 | 100,900 | 174,200 | | | 275,100 | | |
| 1962 | 17,100 | 118,000 | 166,200 | | | 284,200 | | |
| 1963 | 14,700 | 132,700 | 160,200 | | | 292,900 | | |
| 1964 | 13,900 | 146,600 | 150,900 | | | 297,500 | | |
| 1965 | 10,600 | 157,200 | 144,700 | | | 301,900 | | |
| 1966 | 10,100 | 167,300 | 140,800 | | | 308,100 | | |
| 1967 | 10,900 | 178,200 | 147,700 | | | 325,900 | | |
| 1968 | 12,800 | 191,000 | 160,800 | 265,000 | | 351,800 | 456,000 | |
| 1969 | 12,600 | 203,600 | 204,100 | 317,000 | | 407,700 | 520,600 | |
| 1970 | 13,100 | 216,700 | 246,100 | 391,000 | | 462,800 | 607,700 | |
| 1971 | 13,100 | 229,800 | 273,200 | 520,000 | | 503,000 | 749,800 | |
| 1972 | 13,900 | 243,700 | 273,200 | 520,000 | | 516,900 | 763,700 | |
| 1973 | 13,800 | 257,500 | 276,700 | 520,000 | 634,000 | 534,200 | 777,500 | 900,500 |
| 1974 | 12,600 | 270,100 | 200,000 | 420,000 | 600,000 | 470,100 | 690,100 | 870,100 |
| 1975 | 12,300 | 282,400 | 200,000 | 430,000 | 640,000 | 482,400 | 712,400 | 922,400 |
| 1976 | 14,000 | 296,400 | c | 410,000 | 680,000 | | 706,400 | 976,400 |

[a] Includes miscellaneous $U_3O_8$ receipts from mine waters, heap leach, solution mining, and refining residues.

[b] The reserve estimates since 1961 are based on a chosen cost per pound of $U_3O_8$. Estimates for the period 1952 to 1961, inclusive, are based on the AEC Domestic Uranium Program Circular 5 (Revised). For the period prior to 1952, the basis is arbitrary thickness and grade cut-offs.

[c] $8 reserves are no longer reported because of increased market prices.

Source: ERDA. Statistical Data of the Uranium Industry. Grand Junction, Colorado: U.S. Energy Research and Development Administration, Grand Junction Office, January 1, 1977. p. 24.

TABLE 5-7. ESTIMATED URANIUM ORE RESERVES, JANUARY 1, 1977

| Cutoff Costs Dollars/lb. $U_3O_8$ | Tons $U_3O_8$ |
|---|---|
| \$10 | 250,000 |
| \$15 | 410,000[a] |
| \$30 | 680,000[a] |
| \$50 | 840,000[a] |

This table does not include by-product uranium (approximately 140,000 tons of $U_3O_8$ available through the year 2000).

[a] Includes the lower cost reserves.

Source: ERDA. Statistical Data of the Uranium Industry. Grand Junction, Colorado: U.S. Energy Research and Development Administration, Grand Junction Office, January 1, 1977. p. 26.

TABLE 5-8. POTENTIAL RESOURCES (TONS $U_3O_8$), JANUARY 1, 1977

| Class | \$10[a] | \$15[a] | \$30[a] | \$50[a] |
|---|---|---|---|---|
| Probable | 275,000 | 585,000 | 1,090,000 | 1,370,000 |
| Possible | 115,000 | 490,000 | 1,120,000 | 1,420,000 |
| Speculative | 100,000 | 190,000 | 480,000 | 540,000 |
|  | 490,000 | 1,265,000 | 2,690,000 | 3,330,000 |

[a] Includes lower cost resources.

Source: ERDA. Statistical Data of the Uranium Industry. Grand Junction, Colorado: U.S. Energy Research and Development Administration, Grand Junction Office, January 1, 1977. p. 43.

"speculative" is in new provinces or new formations. The estimates of speculative potential, made solely on geologic inference for unexplored areas, have a reliability considerably less than either probable or possible potential estimates for areas in which considerable exploration has occurred.

To indicate the energy represented by these reserves, a typical 1000 megawatt electric (Mwe) nuclear reactor requires 250 tons of yellowcake per year.[1] (Yellowcake is the uranium oxide product from refining uranium ores.) Therefore, the presently licensed capacity of approximately 45,451 Mwe would exhaust the nation's $10 per pound reserves in about 22 years. If the nation achieves the 142,000 Mwe capacity projected by the Federal Energy Administration for 1985,[2] existing $15 per pound reserves would last only about 15 years.

Table 5-9 presents estimates of the relationships between uranium needs and years of supply from 1977 to 1984. These projections make the accuracy of uranium reserve estimates a critical issue. Part of the debate revolves around the government's procedures for estimating reserves. Responsibility for these estimates rests with ERDA which publishes a yearly estimate.[3] The data base for the estimate is proprietary reserve information provided on a voluntary basis by private companies. ERDA makes its own reserve estimates based on the company-supplied information. ERDA judges the reasonability of the company's estimates by a comparison with its own estimates.

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[1] Nuclear Regulatory Commission. Operation of Bear Creek Project, Rocky Mountain Energy Company, Docket No. 40-8452. Washington, D.C. Nuclear Regulatory Commission, Office of Nuclear Materials Safety and Safeguards. June 1977. p. 10-21.

[2] *Ibid.*, p. H-3

[3] Atomic Energy Commission. Environmental Survey of the Uranium Fuel Cycle, Washington. Government Printing Office. 1974. p. 1.

TABLE 5-9. $U_3O_8$ NEEDS FOR PROJECTED NUCLEAR REACTOR FUEL REQUIREMENTS

| Date | Tons of $U_3O_8$ Needed per Year[a] | Number of Years the Estimated Reserves (1/1/77) Will Last at the Given Nuclear Capacity | | |
|---|---|---|---|---|
| | | $10 per pound | $15 per pound | $30 per pound |
| 1977 | 17,400 | 14.4 | 23.6 | 39.1 |
| 1980 | 31,400 | 5.9 | 11 | 19.6 |
| 1984 | 34,900 | 1.4 | 6 | 13.7 |

Source: [a]Stanford Research Institute. Chemical Economics Handbook. Menlo Park, California: Stanford Research Institute, Chemical Information Services, May 1977. p. 793.1000N

However, apparently no uniform data collection method or reserve estimate method exists in the uranium industry.[1]

In addition to the data collected by ERDA, other studies have analyzed the U.S. uranium reserves on the basis of a higher $U_3O_8$ cost. The statistics contained in this analysis were originally taken from published AEC data. In addition to these reported quantities, large amounts of uranium are considered likely to exist in present producing areas at a greater depth and lower grade and in new producing areas considered potentially productive by geologists.[2]

For the purpose of this study, it was assumed that $U_3O_8$ might be economically attractive at a cost of up to $100 per pound. The amount of higher grade uranium ore which could be extracted at these costs was estimated on depth considerations by Electric Power Research Institute and reported in Electric Power Research Institute, Uranium Resources to Meet Long Term Uranium Requirements, (November, 1974).[3] The quantity of the lower grade resources which could be recovered at this cost is not included in the estimates. The effect of this omission is to make the estimates conservative and increase confidence in the values. These estimates do, however, include quantities assumed to be present in nonproducing areas. These quantities are included due to the early stage of uranium exploration and the probability that the full extent of the deposit has not been established. The factor used for these estimates in unknown areas is 2.77 (*i.e.*, the estimate is that there is 2.77 times as much material outside of the known district as in it).

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[1] In an effort to provide more reliable reserve estimates, the AEC undertook the National Uranium Resource Evaluation program for a comprehensive assessment of U.S. uranium resource potential (AEC, n.d.). Problems in arriving at generally accepted estimates are illustrated by a preliminary study of the San Juan Basin in New Mexico. The AEC estimated that this basin contained 740,000 tons of $U_3O_8$ at a price of $30 per pound but 36 independent geologists reviewed the study and their estimates were 290,000 tons less than the AEC estimate. Conversely, some industry critics contend that the overall domestic resource estimates of the government are low.

[2] Electric Power Research Institute, Uranium Resources to Meet Long Term Uranium Requirements. EPRI SR-5, PB 239 515, Springfield, VA. Nat'l. Tech. Inf. Service. 1974. p. 4.

[3] *Ibid.*

Tables 5-10 and 5-11 summarize the uranium estimates for the higher cost $U_3O_8$. In Table 5-10 two numbers, along with a subjective probability factor, are shown for each area. The range results from uncertainty as to the depth distribution of the AEC's estimated potential resources. If all of the AEC estimated potential low-cost resources are deeper than the 400-foot reference depth used for projection, the lower estimate results. If the same percentage of potential resources is above 400 feet as for low cost reserves, the higher estimate results. It is, of course, possible but judged unlikely that an even larger percentage of potential resources than low cost reserves is above 400 feet.

Estimates of recoverable uranium resources have a high degree of uncertainty. Resource estimates vary from year to year, and according to the organization doing the assessment. In very general terms, yearly and organizational estimates vary by as much as 20 to 30 percent. According to ERDA a thorough new resource assessment is now in progress. As previously pointed out, however, the useful size of the resource base is a function of mining technology, costs in many segments of the fuel cycle, and on the technology for uranium use, mainly burning versus breeding.

TABLE 5-10. ESTIMATED REMAINING URANIUM RESOURCES IN INTERMEDIATE AND HIGH GRADE DEPOSITS TO A CUTOFF COST OF $100 PER POUND/AS OF 1/1/73

| | Million Tons | |
|---|---|---|
| | Low | High |
| In the known producing areas | 3.5(.90)[a] | 7.7(.10)[a] |
| In the total United States | 13.2(.50)[a] | 28.9(.05)[a] |

[a] Numbers in parentheses are the subjective probabilities that the true value is greater than the given value.

Source: Electric Power Research Institute, Uranium resources to meet long term uranium requirements, EPRI SR-5, PB 239 515, Springfield, Virginia: National Technical Information Service, 1974, p. 8.

## TABLE 5-11. ESTIMATED LOWER GRADE URANIUM RESOURCES NOT INCLUDED IN TABLE 1

| Grade Range (% $U_3O_8$) | Tons $U_3O_8$ | |
|---|---|---|
| | In Known Producing Area | In Total United States |
| .15 - .20 | 318,000[a] (.90)[b] | 1,200,000[a] (.50)[b] |
| .10 - .15 | 1,524,000[a] (.90)[b] | 5,700,000[a] (.50)[b] |
| .05 - .10 | 3,773,000[a] (.90)[b] | 14,200,000[c] (.50)[b] |

[a] At the time of this report the average grade of uranium resources recoverable at $8 per pound was 0.213 percent. As much as one half the material estimated here might be recoverable at less than $100 per pound of $U_2O_8$.

[b] Numbers in parentheses are the subjective probabilities that the true values are greater than the given value.

[c] Assumed not recoverable at less than $100 per pound. In practice some would be since some below 0.05 percent material was included in $8 reserves. However, some material above 0.10 percent will not in fact be producible below $100 per pound.

Source: Electric Power Research Institute, Uranium resources to meet long term uranium requirements, EPRI SR-5, PB 239 515, Springfield, Virginia: National Technical Information Service, 1974, p. 9.

### 5.2.5 Location of the Resources

The location of uranium deposits in the western United States is shown in Figure 5-2. As indicated in Table 5-12, two states, New Mexico and Wyoming, contain 86 percent of the proven reserves at $10 per pound. The Colorado plateau (which covers parts of Utah, Colorado, Arizona, and New Mexico) contains the major portion of both proven reserves and potential resources as shown in Table 5-13.

About 68 percent of the $10 per pound reserves are located at depths that require underground mining;[1] the rest can be mined using open pit or solution mining technologies. The higher cost of underground mining generally requires that the deep ores have a higher concentration of uranium before they can be classified as reserves.

### 5.2.6 Ownership of the Resources

In January 1977, approximately 27 million acres of land were classified as being held for uranium exploration and mining by ERDA. As shown in Table 5-14 the lands are divided into various categories of ownership. These categories and an explanation of each is as follows: 1) fee - land claims on private lands or potential claims on federal public domain lands, 2) claims - federal public domain lands that have only been located, 3) state - state owned mineral lands, 4) Indian - lands held by individual Indians or by Indian tribes in a trust status,

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[1] ERDA. Statistical Data of the Uranium Industry. Grand Junction, Colorado: U.S. Energy Research and Development Administration, Grand Junction Office, January 1, 1977. p. 50.

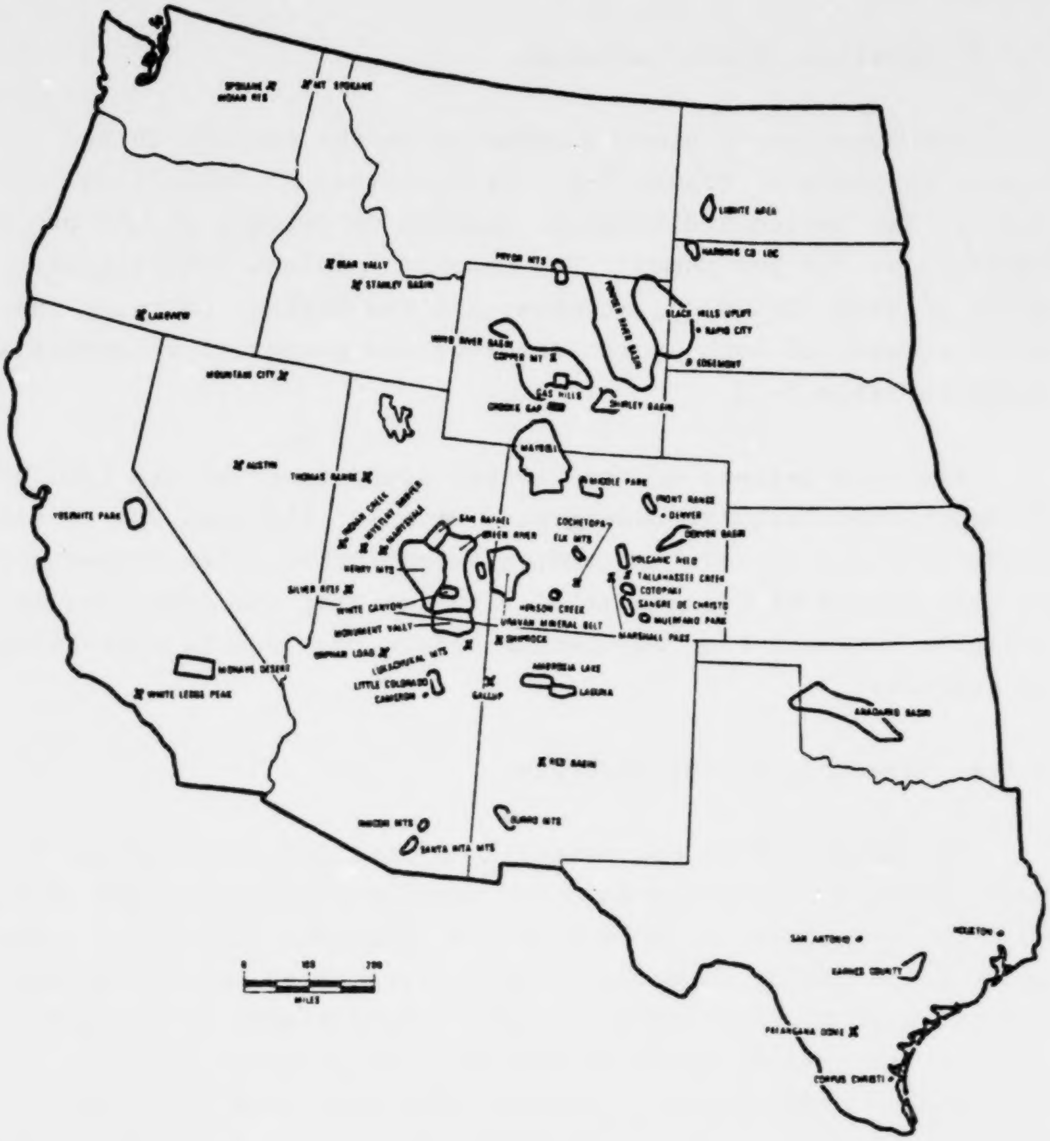
SPOKANE
INDIAN RES
MT SPOKANE
BEAR VALLY
STANLEY BASIN
LAKEVIEW
PRYOR MTS
LIGNITE AREA
HARDING CO LOC
POWDER RIVER BASIN
BLACK HILLS UPLIFT
RAPID CITY
EDGEMONT
WIND RIVER BASIN
COPPER MT
GAS HILLS
CROOKS GAP
SHIRLEY BASIN
MOUNTAIN CITY
MAYBELL
MIDDLE PARK
FRONT RANGE
DENVER
DENVER BASIN
AUSTIN
THOMAS RANGE
YOSEMITE PARK
INDIAN CREEK
MYSTERY MESA
MARYSVALE
SAN RAFAEL
GREEN RIVER
COCHETOPA
ELK MTS
VOLCANIC FIELD
HENRY MTS
TALLAHASSEE CREEK
COTOPAXI
SANGRE DE CHRISTO
HUERFANO PARK
SILVER REEF
WHITE CANYON
HENSON CREEK
URAVAN MINERAL BELT
MONUMENT VALLY
MARSHALL PASS
SHIPROCK
ORPHAN LODE
LUKACHUKAI MTS
AMBROSIA LAKE
MOJAVE DESERT
LITTLE COLORADO
CAMERON
GALLUP
LAGUNA
ANADARKO BASIN
WHITE LEDGE PEAK
RED BASIN
BURRO MTS
SANTA RITA MTS
SAN ANTONIO
HOUSTON
KARNES COUNTY
PALANGANA DOME
CORPUS CHRISTI
0
100
200
MILES

Figure 5-2. Uranium Deposits in the Western United States.

Source: Nuclear Assurance Corporation. U.S. Uranium Economics and Technology. Atlanta, Georgia. Nuclear Assurance Corp., NAC-1. p. VI-6.

TABLE 5-12. ESTIMATED $10 POUND ($U_3O_8$) ORE RESERVES BY STATES, JANUARY 1, 1977

| State | Tons of Ore (Millions) | Grade of Ore (%$U_3O_8$) | Tons of $U_3O_8$ | Percent of Total Tons $U_3O_8$ |
|---|---|---|---|---|
| New Mexico | 55.8 | 0.27 | 152,700 | 61 |
| Wyoming | 55.4 | 0.11 | 62,300 | 25 |
| Texas | 6.2 | 0.12 | 7,300 | 3 |
| Arizona, Colorado & Utah | 5.8 | 0.30 | 17,300 | 7 |
| Others (Calif., N.D., S.D., Wash.) | 5.8 | 0.18 | 10,400 | 4 |
| TOTAL | 129 | 0.19 | 250,000 | 100 |

Source: ERDA. Statistical Data of the Uranium Industry. Grand Junction, Colorado: U.S. Energy Research and Development Administration, Grand Junction Office, January 1, 1977. p.49.

TABLE 5-13. DISTRIBUTION OF 1/1/77 ORE RESERVES BY RESOURCE REGION ($10 RESERVES)

| Resource Region | Tons Ore | % $U_3O_8$ | Tons $U_3O_8$ | % Total Tons $U_3O_8$ | No. Deposits |
|---|---|---|---|---|---|
| Colorado Plateau | 60,000,000 | 0.27 | 161,500 | 64 | 337 |
| Wyoming Basins | 53,800,000 | 0.11 | 60,000 | 24 | 52 |
| Western Gulf Coastal Plain | 6,200,000 | 0.12 | 7,300 | 3 | 37 |
| Northern Plains | 1,000,000 | 0.20 | 2,000 | 1 | 75 |
| *Others: | 8,000,000 | 0.24 | 19,200 | 8 | 25 |
| TOTALS | 129,000,000 | 0.19 | 250,000 | 100 | 526 |

*Includes Colorado & Southern Rockies, Northern Rockies, Northern & Central Basin & Range, Northern Plains, and Sierra Nevada Range.

Source: ERDA. Statistical Data of the Uranium Industry. Grand Junction, Colorado: U.S. Energy Research and Development Administration, Grand Junction Office, January 1, 1977. p.49.

TABLE 5-14. ACRES HELD FOR URANIUM MINING AND EXPLOITATION (IN THOUSANDS OF ACRES)

| Type of Land | Distribution by Land Category<br>1/1/73 | 1/1/74 | 1/1/75 | 1/1/76 | 1/1/77 |
|---|---|---|---|---|---|
| State | 1,859 | 1,945 | 2,968 | 3,385 | 4,635 |
| Claim | 9,679 | 10,290 | 11,634 | 12,605 | 15,067 |
| Acquired | 206 | 145 | 275 | 277 | 293 |
| Indian | 603 | 646 | 635 | 627 | 815 |
| Fee | 5,330 | 5,748 | 5,746 | 6,017 | 6,273 |
| TOTAL | 17,677 | 18,774 | 21,276 | 22,911 | 27,083 |

Source: ERDA. Statistical Data of the Uranium Industry. Grand Junction, Colorado: U.S. Energy Research and Development Administration, Grand Junction Office, January 1, 1977. p. 86.

5) acquired - lands held by the federal government but not in the public domain. Table 5-15 shows the division of acres held for uranium exploration and mining according to state. In a recent Library of Congress report, "Petroleum Industry Involvement in Alternative Sources of Energy", the amount of uranium resources owned by U.S. oil companies was revealed.[1] The report stated that 47% of the U.S. uranium reserves were owned by the oil companies. Kerr-McGee had the largest amount at 21%, followed by Gulf Oil which owned 11.6%.

TABLE 5-15. ACRES HELD FOR URANIUM EXPLORATION AND MINING (IN THOUSANDS OF ACRES) DISTRIBUTION BY STATE 1/1/77

| | |
|---|---|
| Arizona | 1,021 |
| Colorado | 1,852 |
| Montana | 420 |
| New Mexico | 3,885 |
| North Dakota | 128 |
| South Dakota | 810 |
| Utah | 5,498 |
| Wyoming | 11,246 |
| TOTAL | 24,860 |

Source: ERDA. Statistical Data of the Uranium Industry. Grand Junction, Colorado: U.S. Energy Research and Development Administration, Grand Junction Office, January 1, 1977. p. 87.

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[1] U.S. Congress, Senate Subcommittee on Energy Research and Development. Petroleum Industry Involvement in Alternative Sources of Energy, 95th Congress, 1st Session, Publication No. 95-54. Washington, D.C.: U.S. Government Printing Office, September 1977. p. 327.

## 5.3 EXPLORATION

Uranium exploration is usually conducted at two levels - regional exploration for potential uranium occurrences and more local and detailed exploration to define deposits in high probability areas. For the purposes of this discussion, an exploration program for a mine or mines capable of producing 1200 tons of uranium ore per calendar day for 30 years is assumed. The total ore required is therefore about 13 million tons. Most uranium ore occurs in sandstone bodies of fluvial deposits in Wyoming and the Colorado Plateau.

### 5.3.1 Technologies

A typical exploration strategy for uranium deposits consists of the following steps:

1) Selection of promising geographic area and review of existing data,

2) Field work and definition of prospect or prospects,

3) Conduct of drilling program to evaluate prospects,

4) Interpretation of results, formulation of recommendations, and preparation of report.

A broad range of earth science technologies is used in this exploration program. These technologies include geologic, geophysical, geochemical, and earth drilling methods.

### Geologic Techniques

Geologic techniques should provide the central basis for an exploration program. Because most uranium occurs in fluvial sedimentary rocks, modern stratigraphy is the most important geologic subdiscipline. Also important are structural and economic geology. The specific geologic techniques most often used are surface and subsurface mapping of several parameters such as structural configuration of the strata and sand thicknesses.

### Geophysical Methods

The radioactivity of uranium provides a valuable exploration aid. Radiometric prospecting, a type of geophysical prospecting, has served to locate most of the known uranium accumulations. Airborne scintillometers are used extensively in regional exploration, and hand-carried and vehicle-mounted scintillometers are used in both regional reconnaissance and in locating specific local ore bodies. Additionally, borehole scintillometers are used in conjunction with a drilling program for evaluating a prospect.

### Geochemical Methods

Two types of geochemical methods are employed in the exploration of uranium. In the first type, soil or stream sediment samples are systematically collected from a promising area. These samples are then chemically analyzed for their uranium content. Samples from areas underlain by uranium ore bodies will often have a higher-than-normal uranium content, so this type of geochemical survey will often help to delineate potential ore bodies.

The second type of geochemical survey is used for certain types of uranium deposits that have accumulated near the interface between oxidizing and reducing conditions in a sandstone body. The interface can often be delineated by collecting a traverse of samples and subjecting them to geochemical analysis. Once the interface is located, it can often be traced to a location of uranium accumulation.

### Drilling Methods

The drilling methods used in uranium exploration are much the same as those used in coal exploration (See Chapter 3). The standard rotary and core drilling (sometimes with diamond bits) are the two most commonly used methods. For estimating input requirements and output residuals below, a drilling program similar to that proposed by the Exxon Co. will be assumed.[1] This involves the drilling of about 200 holes at an average depth of 1200 feet using 4 to 6 drilling rigs.

## 5.3.2 Input Requirements

### 5.3.2a Manpower Requirements

### Geologic, Geophysical and Geochemical Techniques

A Uranium exploration program should be directed by professional geologists with a supporting staff. A team of three geologists - a stratigrapher/sedimentologist, a geophysicist with expertise in surface and borehole radioactive exploration methods, and a geochemist would probably be needed to apply the combined geologic, geophysical, and geochemical techniques. It is further assumed that the team would be supported by two assistants and a secretary. Table 5-16 presents an estimate of the manpower required to conduct an exploration program for a 1200-ton-per-day uranium mine.

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[1] Planning Support Group, Bureau of Indian Affairs. Uranium Exploration, Mining and Milling Proposal, Navajo Indian Reservation, New Mexico. Volume I, Billings, Montana: Bureau of Indian Affairs, Dept. of the Interior, June, 1976, p. 1-11.

TABLE 5-16: ESTIMATED MANPOWER REQUIREMENTS FOR GEOLOGY-RELATED EXPLORATION FOR URANIUM

| | Geologists (3) | Support Personnel (3) |
|---|---|---|
| | (Man-Years) | (Man-Years) |
| Selection of area and review of existing data | 1.5 | 1.5 |
| Field work and definition of prospect | 1.5 | 1.5 |
| Conduct of drilling program | 1.5 | 1.5 |
| Interpretation of results, formulation of recommendations, and report writing | 1.5 | 1.5 |
| | 6.0 | 6.0 |

Drilling Methods

Exploratory drilling is generally contracted to a well drilling firm. Table 5-17 gives an estimate of the personnel requirements for drilling the exploration holes. This table assumes the drilling contractor would operate four to six crews at a time with service personnel available for clearing and grading trails, surveying line, etc. Exxon estimates the exploration phase of its underground mines in New Mexico to employ 32 people for thirteen years.[1]

TABLE 5-17. ESTIMATED PERSONNEL REQUIREMENTS FOR EXPLORATORY DRILLING

| | |
|---|---|
| Supervisors and foremen | 3 |
| Well drillers | 4 to 6 |
| Drillers helpers | 8 to 12 |
| Truck drivers and/or laborers | 5 to 6 |
| Survey instrumentmen | 2 |
| Survey rodmen or chainmen | 4 |
| Equipment Operators | 2 to 3 |

Source: Planning Support Group, Bureau of Indian Affairs. Uranium Exploration, Mining and Milling Proposal, Navajo Indian Reservation, New Mexico. Volume I, Billings, Montana: Bureau of Indian Affairs, Dept. of the Interior, June, 1976, p. 1.2.

### 5.3.2b Materials and Equipment

The materials needed for geologic techniques are about the same for uranium exploration as for other energy resources. The materials have been described in the coal resource system (see Chapter 3).

Rather specialized equipment is required for exploration in which radioactivity detection is used. The simplest and cheapest device is the hand-held Geiger-Müller counter. Scintillometers, both hand-held and vehicle mounted, are more sensitive and usually yield better results. Airborne scintillometers are used for regional exploration. Borehole geophysical logging equipment, including probes for measurement of radioactivity (gamma ray logs), are usually provided by a contractor specializing in borehole logging and need not be accounted for in this estimate.

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[1] Planning Support Group, Bureau of Indian Affairs. Uranium Exploration, Mining and Milling Proposal, Navajo Indian Reservation, New Mexico. Volume I, Billings, Montana: Bureau of Indian Affairs, Dept. of the Interior, June, 1976, p. III-67.

A relatively sophisticated chemical analysis laboratory is required for geochemical analyses, but existing laboratories are available and probably need not be provided for a specific exploration program.

The equipment required for the drilling part of an exploration program is given in Table 5-18. This estimate is for four to six drilling crews operating at a time.

TABLE 5-18. EQUIPMENT REQUIRED FOR EXPLORATORY DRILLING

| | |
|---|---|
| Drilling rig, rotary, rated for 2,000 ft. | 4 to 6 |
| Water truck, gasoline | 2 to 3 |
| Service vehicles - 3/4-ton, gasoline | 6 to 8 |
| D-8-type crawler tractor with dozer, diesel | 2 to 3 |
| Truck and trailer, diesel | 2 to 3 |
| Survey carryall, gasoline | 2 |
| Misc. small welders, pumps and generators | 10± |

Source: Planning Support Group, Bureau of Indian Affairs. Uranium Exploration, Mining and Milling Proposal, Navajo Indian Reservation, New Mexico. Volume I, Billings, Montana: Bureau of Indian Affairs, Dept. of the Interior, June, 1976, p. 1.1.

### 5.3.2c Economics

The costs for uranium exploration include drilling, drill roads, drill site preparation, geological and other technical support, sampling and drill hole logging. In 1976 these costs ranged from $1 to over $25 per foot drilled. The average cost was $3.13 per foot.[1] Assuming 200 wells of an average depth of 1200 feet, the total exploration costs would be $751,200.

### 5.3.2d Water Requirements

The major water requirements for uranium exploration would result from the drilling operations. These operations would require approximately 3900 gallons per well for making drilling muds, assuming an average well depth of 1200 feet. For a 200 well exploration activity the total water requirement would be about 780,000 gallons. A 1200 ft well could be drilled in one to two days.[2]

### 5.3.2e Land Requirements

There are short term requirements for land use in exploration drilling. About 1/4 acre of land is required for each drill hole.[3] The 200 drill sites would require 50 acres of land which would appear unsightly until reclaimed. Approximately 60 to 80 miles of one lane trails would be needed to reach the drilling sites.[4]

### 5.3.2f Ancillary Energy

The main energy requirement for the exploration activity is the drilling operation. Exxon has estimated that it will require

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[1] ERDA. Statistical Data of the Uranium Industry. Grand Junction, Colorado. U.S. Energy Research and Development Administration, Grand Junction Office. January 1, 1977. p. 83.

[2] Planning Support Group, Bureau of Indian Affairs. Uranium Exploration, Mining and Milling Proposal, Navajo Indian Reservation, New Mexico. Volume I, Billings, Montana. Bureau of Indian Affairs, Department of the Interior. June, 1976. p. III-21.

[3] *Ibid.*, p. III-3.

[4] *Ibid.*, p. 1.1.

60,000 gallons of liquid hydrocarbon fuels per year for the drilling crews.[1] Using a heating value of 139,000 Btu/gal[2] of fuel, the energy requirements are then $8.34 \times 10^9$ Btu/year.

### 5.3.3 Outputs

A relatively small quantity of output residuals are generated during uranium exploration activities. The impact of these activities with respect to air emissions, water effluents, solid wastes, noise pollution and occupational health and safety is discussed in the following sections.

### 5.3.3a Air Emissions

The major source of air emissions resulting from uranium exploration is the operation of various types of machinery. In particular, drilling rigs, trucks, and bulldozers are operated. All use internal combustion engines which exhaust pollutants to the atmosphere. These pollutants include particulates, nitrogen oxides, carbon monoxide, unburned hydrocarbons, lead and sulfur dioxide. The quantity of these pollutants is small compared to the quantities of mining and milling air emissions which follow a successful exploration program. For example, the greatest quantity of pollutant for a 208 hp diesel powered drill rig would be about a 6.4 lb/hr release of nitrogen oxides.[3]

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[1] Planning Support Group, Bureau of Indian Affairs. Uranium Exploration, Mining and Milling Proposal, Navajo Indian Reservation, New Mexico. Volume I. Billing, Montana. Bureau of Indian Affairs, Department of the Interior. June, 1976. p. 1.1.

[2] Battelle Columbus Laboratories. Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing (Phase 5 - Energy Data and Flowsheets, Intermediate - Priority Commodities). Columbus, Ohio: Battelle Columbus Laboratories, September 10, 1975.

[3] U.S. EPA. Compilation of Air Pollutant Emission Factors. Second Edition. Research Triangle Park, North Carolina. U.S. Environmental Protection Agency, Office of Air and Waste Management. February, 1976.

In addition to the emissions from machinery operation, the moving equipment would produce dust clouds. The severity of this dusting would depend on the turbulence created by the vehicles, weather conditions, and the condition of the roadway. The effect of this emission should be minimal due to the small number of vehicles which would be scattered over a wide area.

### 5.3.3b Water Effluents

The exploration activity causes several types of impacts on water resources. Drilling site access roads could cause erosion which would affect surface water runoff characteristics. The presence of mud pits and drill pads could also cause small changes in local surface water runoff characteristics.

In most cases, exploratory drilling will pass through several aquifers as drilling progresses deeper into the ground. Because of a difference in hydraulic pressures, water could leak through the holes between aquifers contaminating one aquifer with water from another. To prevent aquifer contamination or depletion, all drill holes should be sealed with heavy drilling mud and/or cement.

### 5.3.3c Solid Wastes

Solid waste in the form of eroded surface sand could occur if proper reclamation procedures were not implemented following the exploratory drilling. The drill sites would have to be filled and reseeded. The trails to exploration drill holes would have to be reclaimed to prevent erosion from wind and water.

### 5.3.3d Noise Pollution

The noise sources associated with uranium exploration which would produce measurable effects on the environment would be the equipment used for drilling the test holes, the equipment used to prepare and restore drill hole sites, facilities used to maintain the equipment, and vehicles used to transport personnel and supplies to the drilling sites.[1] Table 5-19 gives the noise-producing characteristics of representative exploratory drilling equipment at distances of 50, 500, and 1000 feet.

The drilling rig would be expected to produce the most noticeable noise because it would be operated for longer continuous periods than other types of equipment. The time to drill a test hole varies from one-half day for a shallow hole to as much as a week for a deep hole.[2] The average test hole of 1200 feet depth would require one to two days of drilling.[3]

The noise associated with site preparation and restoration would be temporary. Noise related to transportation of equipment and personnel would be transient. No single location would be exposed for extended periods of time to noise from equipment maintenance as this activity would be performed in the field.

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[1] Planning Support Group, Bureau of Indian Affairs. Uranium Exploration, Mining and Milling Proposal, Navajo Indian Reservation, New Mexico. Volume I. Billings, Montana. Bureau of Indian Affairs, Department of the Interior. June, 1976. p. III-19.

[2] *Ibid.*, p. III-21.

[3] *Ibid.*, p. III-21.

## TABLE 5-19. NOISE-PRODUCING POTENTIAL OF EQUIPMENT ASSOCIATED WITH TEST HOLE DRILLING

| Equipment | Sound Pressure Level, dBA[(a)] | | |
|---|---|---|---|
| | 50 ft | 500 ft | 1000 ft |
| Air Compressor | 75-81 | 55-61 | 49-55 |
| Back-hoe | 75-85 | 55-65 | 49-59 |
| Crane | 75-83 | 55-63 | 49-57 |
| Bulldozer | 75-80 | 55-60 | 49-54 |
| Generator | 75-78 | 55-56 | 49-50 |
| Pump | 75-76 | 55-56 | 49-50 |
| Truck | 75-91 | 55-71 | 49-65 |
| Drilling Rig | 75 | 55 | 49 |

Note: 1. There will be variations in these values because of atmospheric effects. The changes will be measurable at distances of 1000 feet and will depend on temperature, humidity, wind and noise-frequency characteristics.

2. The lower levels shown are recommended by the U.S. General Service Administration as the maximum level for equipment purchased after January 1, 1975.

(a) Sound pressure level in dBA re $2 \times 10^{-5}$ Newton/m$^2$, or $2 \times 10^{-4}$ dynes/cm$^2$.

Source: Planning Support Group, Bureau of Indian Affairs. Uranium Exploration, Mining and Milling Proposal, Navajo Indian Reservation, New Mexico. Volume I, Billings, Montana. Bureau of Indian Affairs, Department of the Interior. June, 1976. p. III-20.

### 5.3.3e Occupational Health and Safety

The potential for safety hazards in an exploration operation would be similar to those associated with other small drilling operations. This would include hazards from moving equipment and environmental concerns such as overexposure to severe weather and the danger of poisonous reptiles.

### 5.3.4 Social Controls

As indicated in the resource description, ownership of uranium lands in the U.S. may be by federal government, state governments, Indian tribes or individual Indians, Railroads, or private individuals or corporations. The rules and regulations governing how uranium lands are made available to private parties for exploration and development vary according to the ownership of the land on which the mineral is located. The following sections will discuss the applicable rules and regulations to the various forms of land ownership.

Federal laws and regulations pertaining to the ownership and control of uranium resources apply to four categories of lands:

1) Public Domain: Lands subject to disposal or sale under the general land laws of the U.S., but not including either reserved lands, withdrawn lands or coastal lands below the low water mark;

2) Reserved: Lands that have been set apart by the Congressional or Executive branches for a special public use such as national forests, Indian and military reservations, etc.;

3) Withdrawn: Lands temporarily removed from the public domain by special legislation, usually for conservation purposes; and

4) Acquired: Lands that were never a part of the public domain or that were once public but owned either privately or by a state government when acquired or reacquired by the federal government.

Most of these public lands are managed by the Department of the Interior (DOI), generally by its Bureau of Land Management (BLM). A majority of Indian lands are owned in a trust status in which the federal government is the trustee and the Indian tribes or individual Indians who own lands or interests in lands are the beneficiaries. In the case of these lands, Interior's Bureau of Indian Affairs (BIA) also has responsibility. Other agencies with primary land management jurisdiction over public lands are the Forest Service in the Department of Agriculture, and the Corps of Engineers in the Department of Defense.

As outlined by DOI, the principal goals and objectives of federal management of public minerals are: to assure "orderly and timely resource development," including promotion of exploration, encouragement of development compatible with other land uses, and maximum ultimate recovery; to protect the environment, including conducting exploration and production activities with maximum environmental concern, assuring rehabilitation of lands, assuring public safety; and to insure the public a "fair market value" return on the disposition of its resources, including evaluation procedures prior to approval of applications, leases, etc., according to "net public resource value" criteria.[1]

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[1] U.S. Congress, Senate Committe on Interior and Insular Affairs. Federal Leasing and Disposal Policies. Hearing pursuant to S. Res. 45, A National Fuels and Energy Policy Study, 92nd Congress 2nd Session, June 19, 1972, pp. 17, 173-174.

Each of the above goals and objectives is covered in some manner by specific legislative acts.

As noted above, a large percentage of the estimated uranium resources are located on public domain lands. The significance of uranium on these lands is greater than indicated by percentage estimates because uranium originally found on public domain claims which have since been patented is included under the category of private lands.

### 5.3.5 Exploration on Federal Lands

Since the method of obtaining minable uranium lands is controlled by the Mining Law of 1872, which has been explained in Section 2.2 of Chapter 2, this section will only treat the specific exploration requirements not discussed earlier. The exploration procedures can be divided into two categories, those without exploration permits and those with such permits.

### 5.3.5a Uranium Exploration Permits

Although 1872 General Mining Law was written without mentioning an exploration permit and in fact was to allow unhampered prospecting, there are certain situations where a permit is required. The discussion that follows will explain some key points, within the provisions.

In August of 1974, the Forest Service (FS) published regulations for the use of surface lands in conjunction with mining under the 1872 law.[1] These regulations are applicable only to the public domain lands that are within the boundaries of a national forest, or that land co-terminous with the Forest Service's jurisdiction. Only the use of earth moving equipment will bring the regulations into play, and the requirement is for the explorer to file a "notice of intent" with the district ranger.[1]

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[1] 39 Fed. Reg. 31317 (1974); codified at 36 C.F.R. § § 2521 *et seq.* (1975).

Once the threshold requirement of earth moving equipment is reached, and if significant surface disturbance is anticipated, then a "plan of operations" is required.[2] The contents of the plan are set out in the regulations[3] and summarized as follows: 1) names and addresses of operators or lessees, 2) map of proposed location and disturbances, 3) description of the operations including means and time frame. Finally, the regulations require that an environmental analysis be undertaken to determine whether an EIS need be filed.[4]

Because the 1872 Mining Law is not applicable to the acquired lands within the national forests, neither are the previously mentioned forest service regulations. The acquisition of minerals on such lands are controlled by the Reorganization Plan No. 3 of 1946[5] with permitting procedure regulated primarily by DOI. Prospecting permits and the associated leasing procedure on acquired national forest land is handled similarly to the procedures on other acquired lands except for one item. Although the BLM and the USGS issue the permits, they can only be approved by the Secretary of the Interior upon the advisement of the Secretary of Agriculture (parent to the Forest Service, and having the duty to protect the national forests).

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[1] McGee, B., "Uranium Exploration and the Fission of the Permit System," RMMLI Proceedings 1976: 7-9.

[2] 36 C.F.R. § 254.4(a) (1975).

[3] 36 C.F.R. § 252.4(c) (1975).

[4] 36 C.F.R. § 252.4(f) (1975).

[5] § 402; 60 Stat. 1099.

Another subcategory within the Forest Service area of operation is its regulation of exploration on wilderness areas.[1] Set up by the Wilderness Act,[2] the wilderness areas are to remain open to mining until December 31, 1983.[3] The primary source of regulation for these areas is the previously mentioned FS regulations. This occurs because wilderness areas are found within national forests or if not the access points are usually through the national forests making the FS's regulations on routes of travel and mode of travel applicable. Two additional agencies have control over wilderness areas, the U.S. Fish and Wildlife Service and the National Park Service,[4] both under the Department of Interior. Where the FS regulations are used in connection with a wilderness area, it can be expected that the environmental problems will require a plan of operation.

Until the Federal Land Policy and Management Act of 1976[5] (The Organic Act) the public lands administered by the BLM under the DOI were not regulated as to mineral development. The prospector under the mining law (1872) and its regulations was not required to notify the BLM of the prospecting or even the removal of ore.[1] The Organic Act however, does place requirements on the Secretary of the Interior to promulgate regulations necessary to carry out the purposes of the Act[2] and to take any action necessary to prevent undue degradation of the lands.[3] Proposed rules under the Organic Act[4] applicable to uranium exploration on BLM administered lands were published in December, 1976. These rules include a requirement that a notice of intent be filed with BLM prior to any mining operation (including exploration) which might cause significant disturbance of surface resources.[5] BLM must determine whether the operation will cause significant disturbance, and if so, notify the operator within 15 days that a Plan of Operations is required. If a Plan of Operations is required, it must be submitted and approved before work begins and be accompanied by a bond adequate to cover the estimated cost of rehabilitation of disturbed areas.[6]

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[1] A wilderness area is "an area where the earth and its community of life are untrammeled by man, where man himself is a visitor who does not remain." 16 U.S.C.A. § 1131 (c) (1970).

[2] Wilderness Act of 1964, 16 U.S.C.A. §§ 1131 *et seq.* (1970?).

[3] 16 U.S.C.A. § 1133 (d) (3). (1970).

[4] In addition, Congress recently passed the Act of September 28, 1976, 90 Stat. 1342 whereby the remaining areas of the National Park System were closed to new exploration. The Act also authorized the writing of regulations to control the development of existing mineral claims in the park areas. See Proposed Rules 41 Fed. Reg. 49862 (Nov. 11, 1976).

[5] Pub. L. No. 94-579, 90 Stat. 2743 (codified as 43 U.S.C.A. §§ 1701 *et seq.* (Supp. 1976).

As was described earlier, the 1872 Mining Law is not applicable to acquired lands, therefore the procedures are somewhat different and are set out in the Reorganization Plan No. 3 of 1946. The prospecting permit granted under this plan gives the holder the exclusive right to prospect[7] and upon the discovery of a valuable deposit, the permittee is entitled to a preference right to lease.[8]

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[1] 43 C.F.R. Group 3800 (1975).

[2] Organic Act of 1976, § 310, 43 U.S.C.A. § 1740 (Supp. 1976).

[3] Id. § 302(b), 43 U.S.C.A. § 1732(b) (Supp. 1976).

[4] Federal Land Policy and Management Act of 1976 (P.L. 94-579; 90 Stat 2743; 43 U.S.C. 1701).

[5] 43 C.F.R. 3809.1-1, Federal Register. December 6, 1976, p. 53429.

[6] 43 C.F.R. 3809.2, Federal Register. December 6, 1976, p. 53431.

[7] 43 C.F.R. § 3510.1-2 (1975).

[8] 43 D.F.R. § 3510.1-1 (1975).

## 5.3.5b Uranium Location Under the Mining Law of 1872[1]

A. Determine if the land is available for claim work and filing. By the use of the Federal Land Office records of the District where the land is located, it should be determined if the land has generally been withdrawn from the application of the 1872 Mining Law. It is advisable to also check the records of the Washington, D.C. office. The following entries in the records will place doubt on the validity of any mining claim: a preexisting patent, national forests, stock driveways, reservoirs, water sources, roads, trails, power lines, Wild and Scenic River, Fremont Trail, Oregon Trail, historic point, withdrawn lands for other purposes, reserved lands and Public Land Sales Act.

B. Comply with discovery requirements. By federal law, no "location" can be made until after discovery has been accomplished.[2] Although these numerous court cases and departmental decisions[3] on the subject of what constitutes discovery be of sufficient quantity and quality to justify a prudent man in the expenditure of his time and money with reasonable expectation of success in developing a paying mine.[1] Further no rights vest until discovery has been made.[2]

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[1] An adaptation of a paper by R. Lawren Moran and David G. Ebner presented at the Uranium Exploration and Development Institute held in Denver, CO, Nov. 18-19, 1976. See paper 2, Rocky Mountain Mineral Law Foundation, 1976.

[2] 30 U.S.C.A. § 23 (1970?). Court decisions have stated: (1) surface indications and geological inferences do not show a discovery, *Henault Mining Co. v. Tyak*, 419 F. 2d 766 (9th Cir. 1969), but rather the actual presence of deposits within each claim must be shown, *U.S. v. Jones*, 2 I.B.L.A. 237, 239 (1971); (2) that the deposit must reach a point of becoming development rather than only justifying further exploration, *Barton v. Morton*, 498 F. 2d 288 (9th Cir. 1974); (3) that there be reasonable probability for developing a mine by comparing the quantities and quality of the deposit, *U.S. v. Coleman*, 390 U.S. 599 (1968); (4) that reasonable probability exists that the ore can be mined at a profit, *U.S. v. N.J. Zinc*, 74 I.D. 191 (1967); (5) that the discovery be shown as to each claim, *U.S. v. Snyder*, 72 I.D. 223 (1965), *off'd* 405 F. 2d 1179 (10th Cir. 1968).

[3] Department of Interior, Board of Land Appeals.

Since the states were authorized to administer the public lands within their boundaries under the terms of the 1872 Law, modified procedures were quickly written into the state laws. Those procedures generally required a posting of notice at the discovery site which gave the prospector time to perfect his location. At present the procedures (subject to variations among the states noted below) are: discovery accomplished, point of discovery established with the distance from the sidelines of the claim to the center of the lode or vein may not exceed 300 feet,[3] and some "discovery work" may or may not be necessary.

One final calculation determining what is and what is not a valid discovery must be mentioned. Because the courts are required to listen to cases arising between disputed claims under the above stated laws a body of case law has developed on the subject. Unfortunately the cases must be divided between those where the U.S. is a party and those where it is not. A basic premise of property disputes is that one must depend upon the strength of his own claim rather than attempt to prove invalid the claim of another. In such situations the resolution by a court of the dispute between two claimants in the favor of one proves only the relative relationship of their claims and not the superiority of the winning claimant over all others. In the case of uranium claims this is especially true - requiring the cases to be divided into two groups. Case law concerning disputes between individual claimants would be one category and cases between the claimant and the U.S. government would be the other. The respective opinions of the courts as to what makes a good claim then must be taken only in light of the parties involved.

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[1] Castle v. Wornble, 19 L.D. 455 (1894); U.S. v. Coleman, 390 U.S. 599 (1968). See also G. Reeves, "The Law of Discovery Since Coleman," 21 Rocky Mtn. Mineral Law Institute 415 (1976).

[2] Cole v. Ralph, 252 U.S. 286 (1920).

[3] The 300 feet to side limit is a federal maximum and does not vary among the states.

C. Description of the Claim - The purpose of the claim description is to provide record notice that the claimant is working under the provisions of the law to establish title to the land described. The states vary in their requirements for claim description but generally require that the description allow the claim's boundaries to be determined with reasonable certainty and commonly require that some natural object or permanent monument be incorporated in the description. State law specifics will be described below.

D. Claim Monuments - Marking the claim on the ground serves the purpose of notifying all that the land in that area has been claimed. By federal regulation the four corners of the claim must be marked with monuments. Further the erection of the monuments is part of the location procedure and the prospector certifies that the claim has in fact been marked in the prescribed manner when he signs the location certificate. Again there are some variations among the states.

E. The Location Certificate - The requirements for the location certificate vary by state. By filing the certificate in the public records the locator affirms that he has performed the required acts leading[1] to a valid claim on the land.

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[1] 43 C.F.R. § 3841.4-5(b) (1975).

### 5.3.6 Exploration Permits on Indian Lands

Procedures for obtaining exploration permits for Indian lands are the same as those for federal lands, except that permission from the appropriate Indian agency or authority is also required. Generally the Bureau of Indian Affairs under the DOI is the authority. But more specifically the Superintendent of Indian Affairs, with tribal consent, issues the required exploration permit. Note also that the permits are of limited duration and do not give the permit holder a preference to lease.

### 5.3.7 Exploration Permits on State Lands

Because the primary goal of mineral exploration is the acquisition of a right to develop the mineral, the method of attaining that right determines the exploration procedure. Hence a state which has retained the older mining claim method of mineral rights will also retain the respective prospecting methods. Both the older method and the more recent exploratory permit lease method exist in the western states. This section will deal only with the specifics of the exploration of state lands for uranium; for a discussion of the general procedures see respective sections in Chapter 2.

State uranium disposition statutes may authorize the location or leasing of deposits and, in general, requirements for permits to explore vary according to this distinction. Colorado utilizes a location or mining claim procedure as a first step toward making uranium lands available. Once a discovery is made and notice is posted with the State Board of Land Commissioners, the claimant must within ten days make arrangements for a permit to explore the extent of the discover.[1]

Judicial decision in Colorado has given the locator preferential right to lease after concluding exploration activities. On the other hand, Utah statutorily requires the procurement of a prospecting permit since its state-owned lands and mineral rights thereto are open only through leasing. Prospecting permits in New Mexico, although not provided for in state law, may be issued within the discretion of the state leasing agency. Where a permit is required, the state usually stipulates that a prospecting plan be filed and limits the extraction of minerals prior to leasing except for sampling or other experimental activities.[1] Although the discretionary authority of the agency head varies within the states being considered, the right is usually reserved to cancel a permit when the permittee has not complied with the terms of the permit and applicable state statutes. Montana should also be noted for its statutory ban of the solution extraction of uranium for two years starting 1975. After the two year period the state legislature will decide whether to allow it or not.

The exploration methods available in the western states can be divided into three general categories. Wyoming and Colorado retain some form of the 1872 mining law resulting in prospecting and claim filing. The remaining states fit into two categories: those (Arizona, South Dakota, and Utah) which have specific exploration permits separate from any leasing procedure, and those (North Dakota, Montana, and New Mexico) which require the exploration to be incorporated in the lease itself. The latter states also usually require competitive leasing of their state lands. Those states with separate exploration procedures allow terms usually of one year or less in the permits with extensions available if necessary. In addition to the above permit requirements these permits are required in some of the states for underground mines, etc. Those permits are applicable to all underground mines regardless of mineral sought and are discussed in Chapter 2.

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[1] Verity, Victor, John Lacy, and Joseph Geraud. "Mineral Laws of State and Local Government Bodies," in Rocky Mountain Mineral Law Foundation, ed. The American Law of Mining. New York, N.Y.: Matthew Bender, 1973, Vol. 2, p. 644.

[2] *Ibid.*, pp. 652-656.

The following tables summarize the applicable statutes in each state for uranium exploration. Table 5-20 is a summary of the eight states and Tables 5-21 through 5-29 give detailed information for each state.

## TABLE 5-20. SUMMARY OF STATE LAND EXPLORATION PERMITS

| | Method of exploration | | | Term of permit or lease | Amount of annual work required to retain | Preference given to permittee to lease | Additional permits may be required[4] |
|---|---|---|---|---|---|---|---|
| | File claim | Exploration permit | Exploration within lease | | | | |
| AZ | | X | | 1 yr. renewable | $10/acre/yr[2] | X | |
| CO | | X[3] | | 60 days extensions available | | | X |
| MT | | | X | 10 yrs. renewable | | N/A | X |
| NM | | | X | 3 yr. extensions available | | N/A | |
| ND | | | X | 5 yrs. renewable | | N/A | X |
| SD | | X | | 1 yr. renewable | | | X |
| UT | | X | | 1 yr. renewable | $250/6 mos. | | X |
| WY | X | | | | $100/yr. if a placer claim | N/A[1] | |

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[1] The discoverer under these statutes, after filing claim, acquires the land title. If a placer claim the title does not pass until $500 expended on mine.

[2] This amount is increased to $20 per acre per year after the first 2 years.

[3] Although this is a permit type of exploration many of the requirements (*e.g.*, posting of notice on site) of the filing method are retained.

[4] For example: Open mine permits, drilling permits, explosive use permit, etc. See Section 2.3.

## TABLE 5-21. ARIZONA URANIUM EXPLORATION PERMIT[a]

| ITEM | STATUTES | SUMMARY |
|---|---|---|
| Agency | § 27-251 | State Land Department, State Land Commissioner |
| Special Requirements[b] | | |
| Fees | § 27-251 | $25.00 filing fee |
| Rental | § 27-251 | $2.00 per acre up to 640 acres. Permittee must expend at least $10 per acre per year for two years and $20 per acre per year after that |
| Duration | § 27-252 | One year, renewable to a total of five years |
| Bond | § 27-255 | Required, see § 27-255 |
| Discretionary Actions | § 27-255 | Bond amount determined by commissioner to cover surface damage |
| Other Information | | |

[a] Arizona Revised Statutes Annotated, 1956.

[b] The second item in each table indicates special requirements for issuing the permit. A blank in this category reflects a necessity of filing an application with a minimum of information to include the applicant's name, address, and location of the land involved.

TABLE 5-22. COLORADO URANIUM EXPLORATION PERMIT[a]

| Item | Statutes | Summary |
|---|---|---|
| Agency | § 36-1-140 | State Board of Land Commissioners |
| Special Requirements[b] | § 36-1-140 | 1. Discovery<br>2. Posting of notice of discovery on site.<br>3. Notify board within ten days of discovery. |
| Fees | | |
| Rental | | |
| Duration | § 36-1-140 | Sixty days, but extension possible |
| Bond | | |
| Discretionary Actions | | |
| Other Information | § 36-1-140 | At expiration of permit the locator may be required to lease upon agreed-to-terms |

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[a] Colorado Revised Statutes, 1973.

[b] The second item is each table indicates special requirements for issuing the permit. A blank in this category reflects a necessity of filing an application with a minimum of information to include the applicant's name, address, and location of the land involved.

## TABLE 5-23. MONTANA URANIUM EXPLORATION PERMIT[a,c]

| | | |
|---|---|---|
| Agency | § 81-501 | State Board of Land Commissioners |
| Special Requirements[b] | § 81-501 | These lands must be leased by competitive bids to at least fair market value |
| Fees | | |
| Rental | § 81-503 | Set by board, but not less than $2 per acre |
| Duration | § 81-502 | 10 years, renewable every 5 years after that |
| Bond | | |
| Discretionary Actions | | |
| Other Information | § 50-1704 | No person may prospect, initiate construction, or undertake preoperation of solution extraction of uranium for 2 years (from April 8, 1975) |

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[a] Revised Codes of Montana, 1947.

[b] The second item in each table indicates special requirements for issuing the permit. A blank in this category reflects a necessity of filing an application with a minimum of information to include the applicant's name, address, and location of the land involved.

[c] Exploration of Montana lands outside of lease is not allowed, hence the terms above are those of the lease.

TABLE 5-24. NORTH DAKOTA URANIUM EXPLORATION PERMIT[a,c]

| Item | Statutes | Summary |
|---|---|---|
| Agency | § 38-11-02.1 | All agencies of the state are authorized to lease, but Board of University and School Land established standards, policies, terms, conditions, rules, and regulations for such activities. |
| Special Requirements[b] | | |
| Fees | | |
| Rental | § 38-11-02.2 | Set by Board of University and School Land |
| Duration | § 38-11-02.2 | Set by Board of University and School Land |
| Bond | § 38-15-03 | The Industrial Commission may require a bond to satisfy conflicts between mining or oil and gas developers on same land |
| Discretionary Actions | | |
| Other Information | § 38-16 | The State Soil Conservation Committee requires a report of operation annually if it is a surface mine |

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[a] North Dakota Century Code, 1960, as amended.

[b] The second item in each table indicates special requirements for issuing the permit. A blank in this category reflects a necessity of filing an application with a minimum of information to include the applicant's name, address, and location of the land involved.

[c] Exploration of North Dakota lands outside of a lease is not allowed, hence the terms above are those of the lease.

TABLE 5-25. NEW MEXICO URANIUM EXPLORATION PERMIT[a,c]

| Item | Statutes | Summary |
|---|---|---|
| Agency | § 7-9-17 | Commissioner of Public Lands |
| Special Requirements[b] | | |
| Fees | § 7-9-21.1 | $10 |
| Rental | § 7-9-22 | Rent to be set by commissioner but not less than 5¢ per acre during primary and not less than 50¢ per acre secondary |
| | § 7-9-31 | Maximum area in lease - 16 sections |
| Duration | § 7-9-21 | Primary term 3 years, a 2-year extension available but rent is 10 times as much per year. Secondary term for production allowed |
| Bond | § 7-9-25 | Bond set by Commissioner but not less than $5,000 for surface repair |
| Discretionary Actions | § 7-9-34 | Commissioner may use competitive bidding |
| Other Information | § 7-9-19 | In 1955 New Mexico ceased to issue the prospecting permit and all exploration must come under lease procedures above |

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[a] New Mexico Statutes, 1953.

[b] The second item in each table indicates special requirements for issuing the permit. A blank in this category reflects a necessity of filing an application with a minimum of information to include the applicant's name, address, and location of the land involved.

[c] Exploration of New Mexico lands outside of lease is not allowed, hence the terms above are those of the lease.

TABLE 5-26. SOUTH DAKOTA URANIUM EXPLORATION PERMIT[a]

| Item | Statutes | Summary |
|---|---|---|
| Agency | § 5-7-1 | Commissioner of School and Public Lands |
| Special Requirements[b] | § 45-7A-3<br>§ 45-7A-2 | A report of any exploratory well drilled must be sent to Department of Natural Resources (will be kept confidential). |
|  | § 45-7A-2 | Such wells must be capped, sealed, or plugged. |
| Fees | § 5-7-7 | 50¢ per acre |
| Rental | § 5-7-9<br>§ 5-7-7 | 50¢ per acre per year. Maximum of 640 acres. |
| Duration | § 5-7-7<br>§ 5-7-9 | One year, renewable to total of three years |
| Bond |  |  |
| Discretionary Actions | § 5-7-7 | The Commissioner, at his discretion, may refuse to issue permit if in best interests of state |
| Other Information | § 5-7-8 | Priority of issue to earliest application date |
|  | § 5-7-10 | Permitee may not remove any minerals |
|  | § 45-6A-16 | Although South Dakota requires a special permit (at a fee of $25) to use heavy equipment in exploration of the surface; this section specifically exempts state lands from that requirement. (The permit is issued by the State Conservation Commission) |

[a] South Dakota Compiled Laws, 1967.

[b] The second item in each table indicates special requirements for issuing the permit. A blank in this category reflects a necessity of filing an application with a minimum of information to include the applicant's name, address, and location of the land involved.

## TABLE 5-27. UTAH URANIUM EXPLORATION PERMIT[a]

| Item | Statutes | Summary |
|---|---|---|
| Agency | § 65-1-18 | State Land Board |
| Special Requirements[b] | | |
| Fees | | |
| Rental | § 40-1-13 | 160 acres maximum per township, per person, with $250 worth of work completed every six months per townships. No ore to be removed |
| Duration | § 40-1013 | One year maximum, with yearly renewals available |
| Bond | | |
| Discretionary Actions | | |
| Other Information | § 40-6-5 | If developer plans to drill (either exploratory or production), the Board of Oil, Gas and Mining has the authority to require:<br>a) security (for plugging)<br>b) notice of intent to drill<br>c) filing of well logs |

[a] Utah Code Annotated, 1953.

[b] The second item in each table indicates special requirements for issuing the permit. A blank in this category reflects a necessity of filing an application with a minimum of information to include the applicant's name, address, and location of the land involved.

TABLE 5-28. WYOMING URANIUM EXPLORATION (MINING CLAIM)[a,c]

| Item | Statutes | Summary |
|---|---|---|
| Agency | § 30-1 | County clerk in county where claim located |
| Special Requirements[b] | § 30-3<br>§ 30-6 | 1) Sink a shaft at location (or drill)<br>2) Post a sign with name of locator, etc.<br>3) Mark surface boundaries |
| Fees | | |
| Rental | | |
| Duration | § 30-1 | The locator who files this claim (or certificate) owns the minerals in fee (forever) |
| Bond | | |
| Discretionary Actions | | |
| Other Information | § 30-1 | This discovery method is only applicable to minerals (in this case uranium) found in veins.<br>The discoverer has 60 days to file this claim after discovery with the following information:<br>a) name of claim'<br>b) name of discoverer<br>c) location of claim<br>d) amount of surface claimed (appears to be no specific statutory limit) |

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[a] Wyoming Statutes of 1957.

[b] The second item in each table indicates special requirements for issuing the permit. A blank in this category reflects a necessity of filing an application with a minimum of information to include the applicant's name, address, and location of the land involved.

[c] See also uranium placer claims on separate sheet.

TABLE 5-29. WYOMING URANIUM EXPLORATION (PLACER CLAIMS)[a,c]

| Item | Statutes | Summary |
|---|---|---|
| Agency | § 30-10 | County clerk in county where claim located |
| Special Requirements[b] | § 30-10 | 1) Erect sign post with name of location on sign<br>2) Mark boundaries on surface |
| Fees | | |
| Rental | | |
| Duration | § 30-16 | Locator may receive a patent (certificate of ownership) after 5 years or expenditure of $500 |
| Bond | | |
| Discretionary Actions | | |
| Other Information | § 30-12 | Locator must perform not less than $100 worth of work per year on the placer claim |
| | § 30-10 | The locator has 90 days to file this claim with the following information:<br>a) name of claim<br>b) name of locator<br>c) number of acres claimed<br>d) description of land<br>e) date |

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[a] Wyoming Statutes of 1957.

[b] The second item in each table indicates special requirements for issuing the permit. A blank in this category reflects a necessity of filing an application with a minimum of information to include the applicant's name, address, and location of the land involved.

[c] See also uranium mining claims for Wyoming.

## 5.4 MINING

Uranium mining techniques depend on the depth, size, assay, and host formation of the ore body, and some of the basic technologies are similar to those used in coal mining (Chapter 3). Of the 281 uranium sources being worked at the end of 1976, 74 percent were underground mines, 16 percent were open pit mines, and the remaining 10 percent consisted of other sources (*e.g.*, low-grade stock piles, heap leach, mine water, solution mining).[1] In terms of total 1976 ore production, however, underground mines provided 48 percent, open pit mines provided 48 percent, and other sources provided about 4 percent.[2] Thus, although small in numbers, open pit mines produced an amount equal to the yellowcake mined in 1976 by underground mining, since daily production rates from open pit mines are much greater than the rates from underground mines. Currently there is a trend towards open pit and in-situ mining due to the rising cost of underground mining and depletion of resources mineable by underground techniques.

A 1,000-Mwe model reactor requires approximately 250 tons of yellowcake per year.[3] Assuming a $U_3O_8$ concentration in the ore of 0.2 percent, 125,000 tons of ore must be mined each year to supply one 1,000-Mwe reactor. For comparison a 1,000-Mwe coal-fired plant would require more than three million tons of coal per year.[4]

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[1] ERDA. Statistical Data of the Uranium Industry. Grand Junction, Colorado: U.S. Energy Research and Development Administration, Grand Junction Office, January 1, 1977, p. 31.

[2] *Ibid.*

[3] Nuclear Regulatory Commission. Operation of Bear Creek Project, Rocky Mountain Energy Company, Docket No. 40-8452. Washington, D.C.: Nuclear Regulatory Commission, Office of Nuclear Materials Safety and Safeguards, June 1977, pp. 10-21.

[4] *Ibid.*

To quantify emissions, costs, manpower requirements, and other impacts associated with uranium mining, certain assumptions regarding size and operating rate must be made. To satisfy this requirement, a single production rate of 440,000 tons of ore per year (1200 TPCD average) has been assumed. Both the open pit mine and the surface mine are considered to produce ores containing 0.20 percent $U_3O_8$. On the basis of these ore grades and a typical recovery of 93 percent[1] of the $U_3O_8$ at the mill, the mine/mills would produce about 800 TPY (4500 lb/day) of $U_3O_8$ (yellowcake). The yellowcake contains approximately 90 percent $U_3O_8$ (typical value)[2].

### 5.4.1 Open Pit Mining

#### 5.4.1.1 Technology

Open pit mining is used to extract uranium ore from depths ranging from a few feet down to about 400 feet.[3,4,5,6] Although most surface mining operations are less than 400 feet deep, there are some exceptions to the rule. An example of this is

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[1] ERDA. Statistical Data of the Uranium Industry. Grand Junction, Colorado: U.S. Energy Research and Development Administration, Grand Junction Office, January 1, 1977, p. 100.

[2] Nuclear Regulatory Commission. Operation of Bear Creek Project, Rocky Mountain Energy Company, Docket No. 40-8452. Washington, D.C.: Nuclear Regulatory Commission. Office of Nuclear Materials Safety and Safeguards, June 1977, pp. 3-26.

[3] Battelle Columbus and Pacific Northwest Laboratories. Environmental Considerations in Future Energy Growth. Columbus, Ohio: 1973.

[4] "Conquista, Conoco-Pioneer $U_3O_8$ Venture, on stream," Mining Eng. 24(8), 37-41, 1972.

[5] Klemenic, John (U.S. Atomic Energy Commission), Examples of Overall Economics in a Future Cycle of Uranium Concentrate Production for Assumed Open Pit and Underground Mining Operations, TIP-26294. Springfield, Va.: NTIS, 1972.

[6] Youngberg, Elton A. "The Uranium Industry - Exploration, Mining, and Milling," IEEE Trans. Power Appar. Syst. PAS-92 (4) 1201-8. 1973

Humble Oil and Refining Co.'s uranium surface mining operation in Converse County, Wyoming, where the operation extends to a 450 foot depth.[1] A recent study indicates that some surface mining can be done at depths of more than 500 feet.[2]

One significant difference between coal and uranium surface mining is that the ore zone in uranium mines is very irregular and of highly varying quality. Coal seams are generally very well defined. The discontinuities of uranium ore zones dictate using unique mining techniques that are not employed in coal mines. A second difference between coal and uranium mines is that each truckload of uranium ore is graded (measured for radioactivity) as it leaves the pit. The truck then delivers the graded ore to a specified stockpile. Often ore zones are graded in place to facilitate mining operations. The purpose of this ore grading and separation is to control the feed to the mill and thereby insure the most efficient and economical processing.

For shallow surface mining operations, the pits may be mined with the pit walls almost vertical.[3] As the mining operations progress and the open pit gets deeper, the need for sloping walls becomes important - mainly to avert the subsidence of the walls into the pit.

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[1] Humble Oil and Refining Co., Minerals Dept. Highland Uranium Mill, Converse County, Wyoming, Applicant's Environmental Report. Houston, Tex.: 1971.

[2] Clark, Don A. State-of-the-Art - Uranium Mining, Milling, and Refining Industry. Environmental Protection Agency, Rob't S. Kerr Environmental Research Laboratory. Ada, Ok.: 1974.

[3] Youngberg, Elton A. "The Uranium Industry - Exploration, Mining, and Milling." IEEE Trans. Power Appar. Syst. PAS-92 (4), 1201-8, 1973.

After removal and storage of the topsoil for later use in reclamation, large quantities of overburden must be removed. Overburden is classified as shallow, soft overburden and hard, deep overburden.[1] The shallow, soft overburden is stripped by diesel crawler tractors and bulldozed into waste piles. These waste piles are loaded by power shovels or front-end loaders into trucks that transport the overburden to the mine dump or backfill it into mined out areas of the pit. The hard, deep overburden is usually drilled and blasted using wagon drill holes.[2,3] The broken rock is loaded and transported to the mine dump or backfill in a way similar to the stripped overburden. Overburden resulting from surface mining operations averages about 30 cubic yards per ton of ore, but can vary over a very wide range of densities.[4]

The exposed uranium ore, after the overburden is removed, is drilled, broken, and transported to the ore storage area, by the same procedure adopted in overburden extraction. The ore occurrences in the mine are so erratic that tonnage and ore grade vary with location. In attempting to maintain a consistent feed ore grade going to the mill, with a minimum amount of waste, selective mining methods are employed. They include controlled digging, accompanied by ore sampling and probing.[5,6]

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[1] Nuclear Assurance Corp., U.S. Uranium. Economics and Technology, NAC-1, Atlanta, Ga.

[2] *Ibid*.

[3] Youngberg, Elton A. "The Uranium Industry - Exploration, Mining, and Milling," IEEE Trans. Power Appar. Syst. PAS-92 (4), 1201-8, 1973.

[4] Battelle, Pacific Northwest Laboratories. Environmental Considerations in Future Energy Growth. Columbus, Ohio: 1973.

[5] Humble Oil and Refining Co., Minerals Dept. Highland Uranium Mill, Converse County, Wyoming. Applicant's Environmental Report. Houston, Tex.: 1971.

[6] Nuclear Assurance Corp., *op.cit*.

An isometric view of a surface mine showing an ore body, which has been exposed for mining by stripping of the overlying shale and sandstone, is shown in Figure 5-3.[1] As this figure indicates, there are many irregularities and discontinuities in the ore zone. Figure 5-4 summarizes the material flow and effluent flow associated with uranium surface mining operations.[2]

Ground water intrusion is a problem in a number of surface mining operations. Normally, ground water is pumped from the mine to surface evaporation ponds, or treatment units prior to surface discharge.[3] The common practice is to dig a trench (or ditch) several feet deep around the periphery of the pit floor. The water that drains into the ditch is discharged out of the mine.[4] As the mine floor depth is increased a new ditch is dug that is always lower than the mine floor. This procedure is repeated throughout the mining operation.

A very important phase of all surface mining operations is reclamation. As a mining area is abandoned it becomes the receptacle for the overburden that must be removed from active mining sites. Thus reclamation continues at the same pace as the mining operation, lagging behind the mining activities by a fixed time period of one or more months.

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[1] Youngberg, Elton A. "The Uranium Industry - Exploration, Mining, and Milling," IEEE Trans. Power Appar. Syst. PAS-92 (4).

[2] Battelle Columbus and Pacific Northwest Laboratories. Environmental Considerations in Future Energy Growth. Columbus, Ohio: 1973.

[3] U.S. Atomic Energy Commission. Environmental Survey of the Nuclear Fuel Cycle. Springfield, VA.: Nat'l. Tech. Inf. Service, 1972.

[4] Clark, Don A. State-of-the-Art - Uranium Mining, Milling, and Refining Industry. Environmental Protection Agency. Rob't S. Kerr Environmental Research Laboratory. Ada, Ok.: 1974.

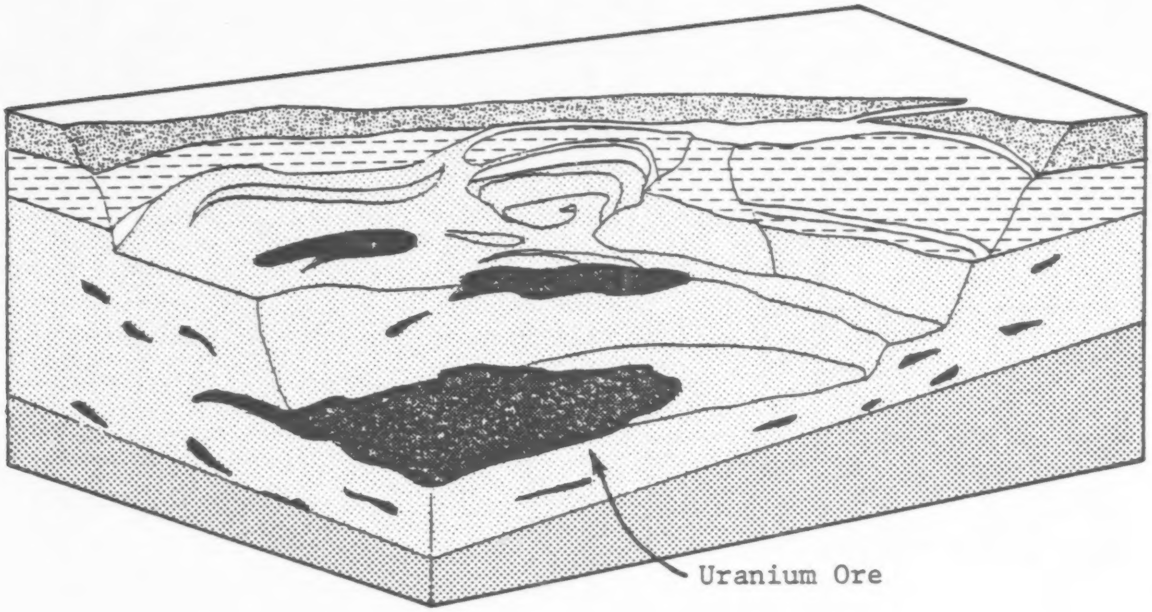

Figure 5-3. Uranium Surface (Open Pit) Mining Operation.

Source: Youngberg, Elton A. "The Uranium Industry-Exploration, Mining, and Milling." IEEE Trans. Power Appar. Syst. Vol. PAS-92(4). 1973. p. 1204.

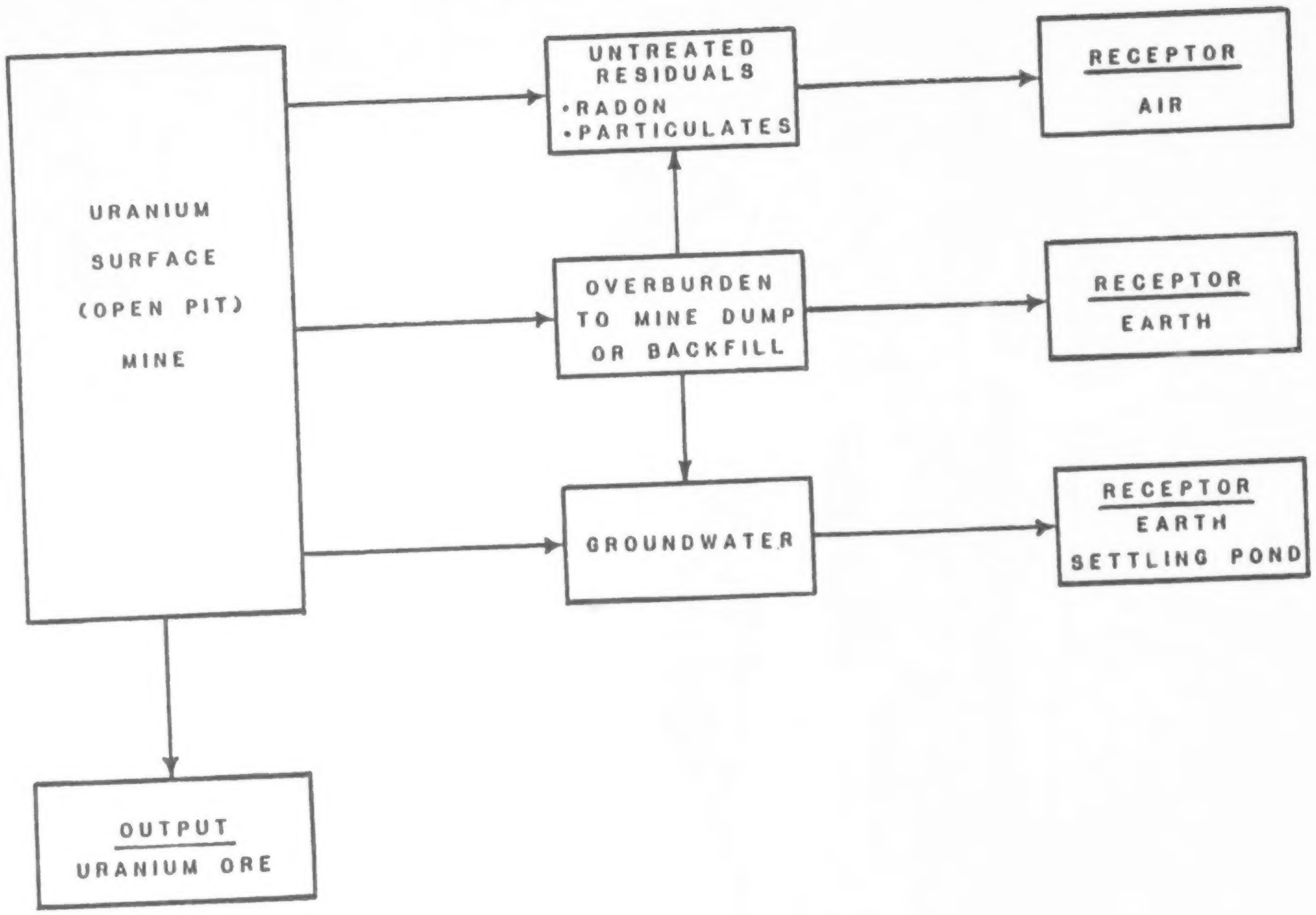
UNTREATED RESIDUALS
•RADON
•PARTICULATES
RECEPTOR
AIR
URANIUM SURFACE (OPEN PIT) MINE
OVERBURDEN TO MINE DUMP OR BACKFILL
RECEPTOR
EARTH
GROUNDWATER
RECEPTOR
EARTH
SETTLING POND
OUTPUT
URANIUM ORE

Figure 5-4. Uranium Surface Mining Block Design

Source: Battelle-Columbus and Pacific Northwest Labs. Environmental Considerations in Future Energy Growth. Columbus, Ohio. 1973.

The available choices of potential land use after mining are greatest in those areas with the best soils and most favorable soil moisture conditions. In general, the reclamation goals include: approximate original contour, restore texture and fertility for use as cropland, establish improved wildlife habitat, develop recreational amenities such as lakes, and convert to urban or industrial use.

Reclamation activities require replacement and compaction of overburden in a manner approximating original land contour. The topsoil which was carefully removed and stored at the beginning of the mining activities is then replaced over the overburden and revegetated with plants suitable to the soil and climatic conditions. Reclamation generally includes irrigation for promoting revegetation, compaction, and dust control. Reclamation activities also must consider runoff and erosion control through the use of contours, dikes, dams and culverts.

#### 5.4.1.2 Input Requirements

The various inputs required for construction and operation of a surface uranium mine will be discussed in the following sections. These inputs include labor, material and equipment, capital, water, land, and any outside energy. Specific assumptions regarding size and ore grade must be made in order to quantify these input variables.

The uranium surface mine considered here has a yearly output of about $4.4 \times 10^5$ tons of uranium ore. This is equivalent to an average daily energy output of $1.12 \times 10^{12}$ Btu, assuming; 1200 TPCD ore production, an ore grade of 0.20 percent $U_3O_8$

(0.7 percent $U_{235}$), a heating value of $71.4 \times 10^{12}$ Btu per ton $U_{235}$ fissioned[1], and a recovery of 93 percent of the $U_3O_8$ in the ore.

### 5.4.1.2a Manpower Requirements

Two phases must be addressed in any discussion of the required labor force: the construction phase and the operating phase. Different skills are required of the workers involved in each phase.

The Bechtel Corporation has estimated the manpower required to build and operate a 1200 ton/day mine.[2] Table 5-30 presents the construction manpower and the proper timing sequence to efficiently-build a uranium surface mine. Table 5-31 presents the number of men required to operate such a facility.

Similarly, the employment predictions for a 1400 ton/day surface mine run by the Rocky Mountain Energy Company call for an 18-month construction period for the mine and mill, and employ an average work force of 150 persons with an expected peak of 250 at the height of activity.[3] Mine operation is expected to employ 175 persons for 11 years.[4] Both sources project approximately the same overall manpower requirements.

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[1] Pratt and Whitney Aircraft. Aeronautical Vest-Pocket Handbook, 10th Ed., 1964.

[2] Carasso, M., et al. Energy Supply Model, Computer Tape. San Francisco: Bechtel, 1975.

[3] Dames and Moore. Environmental Report, Bear Creek Project, Converse County, Wyoming, For Rocky Mountain Energy Company. Denver, Colorado: Rocky Mountain Energy Company, 1975, p. 4-16.

[4] *Ibid.*, p. 8-4.

TABLE 5-30. SCHEDULE OF MANPOWER RESOURCES (MAN-YEARS) REQUIRED TO CONSTRUCT A 1200 TON/DAY SURFACE URANIUM ORE MINE

| Skill | Year 1 | Year 2 | Year 3 | Year 4 |
|---|---|---|---|---|
| Civil Engineers | 2 | 3 | 2 | 2 |
| Mining Engineers | 1 | 2 | 2 | 1 |
| Geological Engineers | 2 | 3 | 2 | 2 |
| Other Engineers | 1 | 2 | 2 | 1 |
| Designers + Draftsmen | 1 | 2 | 1 | 1 |
| Supervisors + Managers | 1 | 1 | 1 | 1 |
| Pipefitters | 1 | 1 | 1 | 1 |
| Electricians | 1 | 1 | 1 | 1 |
| Iron Workers | 1 | 1 | 1 | 1 |
| Carpenters | 1 | 1 | 1 | 1 |
| Operating Engineers | 28 | 31 | 45 | 46 |
| Other Major Skills | 2 | 2 | 3 | 3 |
| Teamsters + Laborers | 16 | 17 | 17 | 7 |
| TOTALS | 58 | 67 | 79 | 68 |

Source: Carasso, M., et al., Energy supply model, Computer Tape, San Francisco, Bechtel, 1975.

## TABLE 5-31. MANPOWER RESOURCES REQUIRED FOR OPERATION AND MAINTENANCE OF A 1200 TON/DAY SURFACE URANIUM ORE MINE

| Skill | Number Required |
|---|---|
| Mechanical Engineers | 1 |
| Mining Engineers | 2 |
| Geological Engineers | 1 |
| Other Engineers | 2 |
| Designers + Draftsmen | 2 |
| Supervisors + Managers | 6 |
| Other Technical | 4 |
| Non-Technical (non-manual) | 28 |
| Electricians | 4 |
| Welders | 4 |
| Operators | 62 |
| Other Major Skills | 32 |
| Other Craftsmen | 20 |
| Teamsters + Laborers | 10 |
| TOTAL | 178 |

Source: Carasso, M., *et. al.*, Energy Supply Model, Computer Tape, San Francisco, Bechtel, 1975.

### 5.4.1.2b Materials and Equipment

Information on the materials required to construct a 1200 ton/day surface uranium ore mine was extracted from Bechtel's "Energy Supply Planning Model."[1] This model predicts that 180 tons of structural steel, 30 tons of reinforcing bars, 90 tons of piping, 100 tons of oil country tubular goods, 10 tons of concrete, and 5100 tons of refined products will be used to build this size mine.

Table 5-32 contains an estimate of the equipment required to operate a surface mining project. Two different surface mining techniques are represented in the table, "scraper/ripper stripping" and "truck/shovel stripping." One of these techniques would be selected for use in mining the ore. Also given are estimates for equipment needed for getting the ore to the mill and for reclamation operations. The equipment requirements have been presented for a 1200 ton/day operation, and were scaled from a 1400 ton/day mine.

### 5.4.1.2c Economics

The capital and operating costs for a 1200 ton/day surface mine are shown in Tables 5-33 and 5-34. These costs were estimated from information provided in a report by Dames and Moore.[2] The economic data in the Dames and Moore report was provided for three different capacity mines in 1975 dollars. This data was adjusted by using CE plant and M&S equipment cost indexes from the "Economic Indicators" given in Chemical

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[1] Carasso, M., et al. Energy Supply Model, Computer Tape. San Francisco: Bechtel, 1975.

[2] Lootens, P. J. Uranium Production Methods and Economic Considerations. Park Ridge, Illinois: Dames and Moore, 1975.

## TABLE 5-32. EQUIPMENT ESTIMATES FOR A 1200 TON/DAY SURFACE MINING PROJECT

| Unit | Capacity | Number Required |
|---|---|---|
| | Topsoil and Overburden Removal Scrapper/Ripper Stripping | |
| Scrapers | 30 yard | 14 |
| Rippers | ~385 H.P. | 2 |
| Pushers | ~385 H.P. | 5 |
| Water trucks | 7,000 to 10,000 gallons | 2 |
| Grader | ~240 H.P. | 2 |
| Drill | 4 3/4-inch holes | 1 |
| Service trucks | Light-duty | 3 |
| Pickups | 3/4 ton | 5 |
| Fuel and lube trucks | 1,000 gallons | 3 |
| | Truck/Shovel Stripping | |
| Shovel | 14 yard | 1 |
| Trucks | 120 ton | 6 |
| Rippers | ~385 H.P. | 1 |
| Grader | ~240 H.P. | 2 |
| Water truck | 7,000 to 10,000 gallons | 2 |
| Drill | 4 3/4-inch holes | 1 |
| Service trucks | Light-duty | 3 |
| Pickups | 3/4 ton | 5 |
| Fuel and lube truck | 1,000 gallons | 2 |
| | Ore Removal | |
| Backhoe | 4 yard | 2 |
| Trucks | 35 ton | 4 |
| Rippers | ~385 H.P. | 1 |
| Road maintenance | Same units as used by the stripping fleets. | |
| Drill and blast | " " " " | |
| Service vehicles | " " " " | |
| Pickups (ore sampling) | 3/4 ton | 2 |
| Wheel loader | 6 yard | 1 |
| | Reclamation | |
| Self-loading scrapers | Caterpillar 633 | 3 |
| Caterpillar tractor | D-9 | 1 |

Source: Nuclear Regulatory Commission. Operation of Bear Creek Project, Rocky Mountain Energy Company, Docket No. 40-8452. Washington D.C.: Nuclear Regulatory Commission, Office of Nuclear Materials Safety and Safeguards, June 1977. p. 3-25

TABLE 5-33. CAPITAL INVESTMENT ESTIMATE FOR A 1200 TON/DAY SURFACE MINE PLANT (1977 dollars)

| Item | Investment Cost ($10^3$ $) |
|---|---|
| Shop/warehouse, surface buildings[a] | 1,629 |
| Office buildings[a] | 179 |
| Access road, 8 miles[a] | 90 |
| Initial haul road, 1 mile[a] | 26 |
| Magazines (explosives storage)[a] | 34 |
| Crusher & loan-out[b] | 365 |
| Electrical supply[a] | 375 |
| Well drilling & pump installation[b] | 46 |
| Piping, 1 mile[a] | 22 |
| Ambulance[b] | 13 |
| Pickups, 3/4-ton[b] | 130 |
| Service & maintenance trucks[b] | 135 |
| Fork lifts[b] | 101 |
| Subtotal | 3,145 |
| Contingency @ 10% | 315 |
| Mining Equipment[b] | 10,207 |
| Total Mine Investment | 13,667 |
| Preproduction stripping[d] | 7,500 |
| ESTIMATED CAPITAL INVESTMENT | 21,167 |

[a] Cost increased by a factor of 1.13

[b] Cost increased by a factor of 1.16

[c] Cost increased by a factor of 1.15

[d] For 10,000,000 tons of overburden @ 125% of estimated operating stripping costs.

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Source: Lootens, D. J. Uranium Production Methods and Economic Considerations. Park Ridge, Illinois: Dames & Moore, 1975.

## TABLE 5-34. ESTIMATED COST SUMMARY FOR A 1200 TON/DAY OPEN-PIT URANIUM MINE (1977 dollars)[a]

| | $ Per Ton Milled |
|---|---|
| Topsoil Removal | 0.06 |
| Stripping | 12.80 |
| Development Drilling | 0.19 |
| Ore Mining | 2.70 |
| Crush and Load-out[b] | 6.23 |
| Reclamation[c] | 0.80 |
| TOTAL MINE OPERATING COST ESTIMATE[b] | 16.78 |

[a] Costs were increased by a factor of 1.10 and 1.07 for labor and supplies, respectively. Labor is assumed to be 57% and supplies 43% or the operating cost, resulting in a factor of 1.14 to be used to scale the costs.

[b] No provision for ore transportation to mill site.

[c] Phillips, P. E. "A Comparison of Open Pit and In-Situ Leach Economics," Presented at the Conference on Uranium Mining Technology. Reno, Nevada, April 28, 1977.

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Source: Lootens, D. J. Uranium Production Methods and Economics Considerations. Park Ridge, Illinois: Dames & Moore, 1975.

Engineering magazine.[1,2] The factors used in adjusting costs are noted in the information given in the tables. The costs for a 1200 ton/day mine were interpolated from the adjusted costs derived for a 500,1000 and 2000 ton/day mine.

### 5.4.1.2d Water Requirements

Water requirements for a surface mining operation would result mainly from two water needs: dust suppression on haulage roads and potable water for personnel. An estimated 40,000 to 50,000 gallons per day would be required for dust suppression at a 1400 ton/day surface mine.[3] Assuming the amount of dust suppression needed varies linearly with mine activity, the water needed for a 1200 ton/day mine would be 34,000 to 43,000 gallons per day. However in most cases the water for dust suppression would be provided by the mine dewatering system which would be producing 860,000 to 2,800,000 gallons of water per day.[4] Occasionally surface mines do not have sufficient ground water, or the ground water is of such poor quality that it requires treatment even before use as a dust suppressant.

Potable water requirements for a 1400 ton/day surface mining operation have been estimated to be about 1000 gallons per day.[5] This water would be provided by a local water well. The water would be treated if necessary to convert it to drinking water quality. Potable water requirements for a 1200 ton/day mine are assumed to be similar to those for a 1400 ton/day mine as the manpower requirements are about the same.

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[1] Chemical Engineering. "Economic Indicators," Chemical Engineering, Vol. 82, (Dec. 22, 1975), p. 116.

[2] *Ibid.*, Vol. 89, (Dec. 5, 1977), p. 7.

[3] Nuclear Regulatory Commission. Operation of Bear Creek Project, Rocky Mountain Energy Company, Docket No. 40-8452. Washington, D.C.: Nuclear Regulatory Commission. Office of Nuclear Materials Safety and Safeguards, June 1977, p. 3-22.

[4] *Ibid.*, p. 3-14.

[5] *Ibid.*, p. 3-22.

### 5.4.1.2e Land Requirements

The largest requirement for open pit mining is for land area. The amount of land area needed for an open pit mining operation varies with the shape of the ore deposit being mined. Larger land areas are required for thin, widely spread deposits than for thick concentrated deposits. If the uranium occurs in separate deposits in an area, the whole area is removed from other use even though mining occurs only at the deposits. The movement of large machinery and the generation of large amounts of noise and dust from the mining would prevent other activity in the area.

The deposit being mined by the Rocky Mountain Energy Company in Converse County, Wyoming represents a typical land requirement of a 1000 ton/day open pit. The pit will be approximately 7600 feet long and will vary in width from 1200 feet in the middle to 800 feet on either end.[1] Topsoil, overburden, and ore will be removed to depths of 160-375 feet below the original surface.[2] The single pit would require about 153 acres of land. As a result of all the mining activity, approximately 575 acres will be needed for the mine pits, 880 acres for overburden piles, 148 acres for topsoil piles, 130 acres for haul roads and settling ponds, and 40 acres for the mine shop.[3]

The mine mentioned above would produce approximately 1000 tons of ore per day for a five year period.[4] However, removal of the overburden would require 14 to 15 months and the mining of nearby ore deposits would remove the land area of the mine from use for an additional five years.[1]

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[1] Dames & Moore. Environmental Report, Bear Creek Project, Converse County, Wyoming, For Rocky Mountain Energy Company. Denver, Colorado. Rocky Mountain Energy Company. 1975. p. 9-8.

[2] *Ibid.*

[3] Nuclear Regulatory Commission. Operation of Bear Creek Project, Rocky Mountain Energy Company, Docket No. 40-8452. Washington, D.C. Nuclear Regulatory Commission, Office of Nuclear Materials Safety and Safeguards. June 1977. p. 4-6.

[4] Dames & Moore, *op. cit.*, p. 9-1.

In uranium surface mining, land areas previously mined and already exhausted of uranium ore are partially reclaimed by backfilling the open pit with overburden materials. At the end of mining operations the last portion of land is not backfilled with soil due to economic reasons.[2] This area typically is allowed to fill with water to form a man-made lake. It can be used for a water impoundment for livestock and wildlife[3] or future recreational benefits[4] if the water in the lake is of good quality. For the surface mine mentioned previously, a lake covering 72 acres would be left following reclamation.

### 5.4.1.2f Ancillary Energy

The energy requirements for a uranium surface mine result from the fuel requirements of the mining equipment and the electrical energy requirements of the mine. Battelle Columbus Laboratories has done a study for the U.S. Bureau of Mines on the energy usage in uranium ore processing.[5] This study estimated that 7,900 kwh of electricity and 1,515 gallons of fuel, oil, and grease are consumed for every net ton of $U_3O_8$.[1] For a 1200 TPCD ore production with an ore grade of 0.20 percent $U_3O_8$, the electrical energy requirement would be 18,960 kwh/day. The fuel, oil, and grease requirement would be 3636 gallons/day, or $0.545 \times 10^9$ Btu/day using a heating value of $0.15 \times 10^6$ Btu/gal.[2]

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[1] Dames & Moore. Environmental Report, Bear Creek Project, Converse County, Wyoming, For Rocky Mountain Energy Company. Denver, Colorado. Rocky Mountain Energy Company. 1975. p. 9-1.

[2] U.S. Atomic Energy Commission. Environmental Survey of the Nuclear Fuel Cycle, WASH-1237. Springfield, VA. National Technical Information Service. 1972. p. A-10.

[3] Dames & Moore, *op.cit.*, p. 9-2.

[4] U.S. Atomic Energy Commission, *op.cit.*, p. A-14.

[5] Battelle Columbus Laboratories. Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing (Phase 5--Energy Data and Flowsheets, Intermediate-Priority Commodities). Columbus, Ohio. Battelle Columbus Laboratories. September 16, 1975.

### 5.4.1.3 Outputs

The outputs associated with a 1200 ton/day surface uranium ore mine are discussed in the following sections. Air emissions, water effluents, solid wastes, noise pollution, and occupational health and safety statistics will be discussed and quantified where possible.

### 5.4.1.3a Air Emissions

Sources of nonradiological air emissions from a uranium surface mine are mainly the heavy-duty, diesel-powered vehicles used in operating the mine which were discussed in Section 5.4.1.2b. The emissions from the internal combustion engines and the fugitive dust generated by equipment operation are the major pollutants released. Using a similar equipment list and emission factors developed by the EPA (EPA Pub. No. AP-42) TVA has estimated the vehicular emissions from surface mining operations. These emission estimates are presented in Table 5-35.

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[1] Battelle Columbus Laboratories. Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing (Phase 5--Energy Data and Flowsheets, Intermediate-Priority Commodities). Columbus, Ohio. Battelle Columbus Latoratories. September 16, 1975. p. 207.

[2] *Ibid.*

## TABLE 5-35. POSSIBLE VEHICULAR EMISSIONS FROM A 1200 TON/DAY SURFACE MINING OPERATION[a]

| | Emissions | | |
|---|---|---|---|
| Pollutant | First shift (lb/hr)[b] | Second shift (lb/hr)[b] | Annual (tons/yr)[b] |
| Particulates | 10.16 | 7.94 | 18.8 |
| Sulfur Oxides | 21.19 | 16.43 | 39.1 |
| Carbon Monoxide | 216.35 | 176.75 | 409.5 |
| Nitrogen Oxides | 291.12 | 138.81 | 538.8 |

[a] Emissions due to gasoline and diesel fuel consumption.

[b] Emissions given in lb/hr are for times when vehicles are operating, whereas the tons/yr figures reflect the schedule of operations for the year.

Source: Tennessee Valley Authority. Draft Environmental Statement, Marton Ranch Uranium Mining. Chattanooga, TN. Tennessee Valley Authority, Division of Environmental Planning. 1975. p. 46-12.

Carbon dioxide emissions would be approximately 3380 lb/hr. This was calculated by assuming that all of the 3636 gal/day of petroleum product requirement (Section 5.4.1.2f) was No. 2 fuel oil containing 87 percent carbon by weight with a density of 7.0 lb/gal, and all the carbon in the fuel is converted to $CO_2$.

Fugitive dust can be expected from blasting, drilling, scraping, loading, transporting, and dumping of overburden and ore, as well as from wind erosion of disturbed areas and overburden material before reclamation. TVA used an emission factor for fugitive dust of 1.4 tons per acre per month.[1] This factor was developed by the EPA from data collected around construction sites in Nevada and Arizona. TVA also used an estimate of 900 acres of unpaved roads, pit areas, and overburden and ore piles for the maximum surface area disturbed by open pit mining activities at any given time. Using the emission factor of 1.4 ton/acre/month, the maximum exposed surface area would produce approximately 1300 tons of total particulate emissions per month (∿3600 lb/hr) if no mitigating measures were taken. In completing an estimate of fugitive dust emissions, TVA quoted a U.S. Bureau of Mines report which estimated that with mitigation, the dust emissions can be reduced by as much as 90 percent.[2] This would then give an estimate of 130 tons per month (∿360 lb/hr) for fugitive dust emissions.

Because of the radioactive nature of the uranium ore, uranium mines have the unique problem of radioactive emissions.

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[1] Tennessee Valley Authority. Draft Environmental Statement, Morton Ranch Uranium Mining. Chattanooga, TN. Tennessee Valley Authority, Division of Environmental Planning. 1975. p. 4.6-4.

[2] *Ibid.*, p. 4.6-5.

As a consequence of uranium ore exposure to the atmosphere during mining operations, radon gas (Rn-222) and its daughters are released to the environment. Rn-222 is the major radioactive nuclide released. An estimate of this release for a surface mine removing ore at a rate of about 364,000 tons/yr (a 1000 ton/day) surface area of 3.8 x $10^6$ $ft^2$ is shown in Table 5-36.

TABLE 5-36. RADIOACTIVE RELEASE OF RADON-222 GAS FROM 364,000 TON/YR URANIUM SURFACE MINING OPERATION

| | Upper limit | Lower limit |
|---|---|---|
| Ore gas | 27.7 Ci/yr | 27.7 Ci/yr |
| Overburden | 1.4 Ci/yr | 1.4 Ci/yr |
| Mine surface | 7409.0 Ci/yr | 4631.0 Ci/yr |
| Total | 7438.1 Ci/yr | 4660.1 Ci/yr |

Note: Ci (curies)

Source: Nuclear Regulatory Commission. Operation of Bear Creek Project, Rocky Mountain Energy Company, Docket No. 40-8452. Washington, D.C. Nuclear Regulatory Commission. Office of Nuclear Materials Safety and Safeguards. June 1977. p. K-7

The radioactive release from overburden and the mine surface is a function of amount of overburden and mine surface area, respectively. These would be about the same for the 1200 ton/day mine described in this section. The Rn-222 gas release from the ore would vary with the mining rate and would be about 33.2 curies (Ci)/yr for a 1200 ton/day mine.

### 5.4.1.3b Water Effluents

Water effluents from an open pit mine are primarily a result of water instrusion into the mine pit. To keep the mine dry while the ore is extracted, water is pumped from the mine to a settling pond. In the pond the water receives treatment prior to discharge to existing surface drainages. A water balance on a typical open pit mine would have an estimated 600 to 1600 acre ft/yr of water from the mine going to a settling pond.[1] From the pond an estimated 33 acre ft/yr would go to evaporation, 45 to 56 acre ft/yr would be used for dust suppression, and 500 to 1500 acre ft/yr would be released to surface drainage.[2]

The water that is pumped from the mine to a settling pond is turbid and carries suspended solids, rock, silicates, Ra-226, and trace uranium ore.[3,4] The item of primary concern with this water is its Ra-226 content although it may be necessary to remove a number of other constituents as well. Some treatment process, such as the use of barium chloride, is utilized for removing radium from the mine water before discharge.[5] The radium precipitated in the settling ponds would be periodically transferred to a tailings pond. Radium content of the mine water could be as high as 100 pCi/l.[6] A typical ambient groundwater concentration of radium would be only 3.3 pCi/l.[7] Concentrations of radium in the water discharged to the environment are generally required to be less than or equal to the ambient concentrations.

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[1] Nuclear Regulatory Commission. Operation of Bear Creek Project, Rocky Mountain Energy Company, Docket No. 40-8452. Washington, D.C. Nuclear Regulatory Commission, Office of Nuclear Materials Safety and Safeguards. June 1977. p. 3-34.

[2] *Ibid.*

[3] U.S. Atomic Energy Commission. Environmental Survey of the Nuclear Fuel Cycle, WASH-1237. Springfield, Va. Natural Technical Information Service, 1972. p. A-17.

[4] Nuclear Regulatory Commission, *op.cit.*, p. 3-30.

[5] *Ibid.*, p. 3-141.

[6] *Ibid.*, p. 3-33.

[7] *Ibid.*, p. 3-30.

To insure that there is no hazardous water discharged to surface drainage or lost through seepage from the settling pond, a proper water monitoring program should be maintained to check surface and underground water quality.[1]

### 5.4.1.3c Solid Wastes

There are very few solid wastes associated with a surface mine other than the overburden that has been removed. Overburden removal is part of the mining operation and the overburden is used in the reclamation activity. Therefore, overburden is not actually considered a solid waste. However, the overburden that is placed back into the mining pit for reclamation is more permeable, even after settling and compaction, than it was before it was disturbed. It also contains many minerals that were previously sealed below the surface. As a result of having been disturbed, the replaced overburden will be less stable, and thus more reactive. Because of this, increased leaching of chemical ions can result. In addition to uranium, moderate to high concentrations of vanadium, selenium, molybdinum, and arsenic can be present in the overburden and are susceptible to leaching.[2]

Because the disturbed fill area will be more permeable than the undisturbed land surrounding it, groundwater flow should be deflected around the reclaimed areas. This would lower the amount of leaching through the disturbed area. An additional consequence of the higher permeability would be an increase in erosion resulting in increased sediment deposition down gradient.

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[1] Nuclear Regulatory Commission. Operation of Bear Creek Project, Rocky Mountain Energy Company, Docket No. 40-8452. Washington, D.C. Nuclear Regulatory Commission, Office of Nuclear Materials Safety and Safeguards. June 1977. p. 3-141.

[2] *Ibid.*, p. 4-5.

### 5.4.1.3d Noise Pollution

The use of heavy machinery and explosives in breaking and loading the overburden is the major source of noise pollution created by open pit mining. Tables 5-37 and 5-38 summarize the major noise producing equipment which are used and the estimated sound levels for the two types of surface mining. Also given is the equivalent noise level, which would occur at a distance of 100 feet from the mine, resulting from all the noise producing equipment. Information in Tables 5-37 and 5-38. was developed from EPA reports No. 550/9-75-014, "Portable Air Compressor Noise Control Technology and Cost Information" and No. 550/9-74-004, "Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety."[1]

In many cases it is necessary to detonate explosives in order to loosen the overburden. Measurements reported by Dames and Moore for the Rocky Mountain Energy Co. indicate that such detonation would produce maximum sound levels of 97 dBA at 500 feet.[2]

The mine would be a source of noise pollution for its entire 10 year life. The mine could be expected to operate 24 hours per day, 7 days a week.[3] Detonation of explosions is generally limited to daylight hours.

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[1] Dames & Moore. Environmental Report, Bear Creek Project, Converse County, Wyoming, For Rocky Mountain Energy Company. Denver, Colorado. Rocky Mountain Energy Company. 1975. p. 5-35, 5-36.

[2] *Ibid.*, p. 5-39.

[3] *Ibid.*, p. 5-36.

## TABLE 5-37. MAJOR NOISE PRODUCING EQUIPMENT AND SOUND LEVELS FOR SURFACE MINING OPERATION (SHOVEL AND DUMP TRUCK)

| Equipment | Usage Factor[a] | Sound level at 50 feet (dBA) |
|---|---|---|
| D9G Caterpillar tractor | .16 | 77 |
| Scraper | .08 | 76 |
| Power shovel | .5[b] | 82 |
| Dump truck | .5[b] | 88 |
| Bulldozers (for clean-up) | .02[b] | 74 |
| Drill | .04 | 84 |
| Air compressor | .04 | 67 |

Equivalent Sound Level: 85 dB at 100 feet

[a] Percentage of time in noisiest operating mode

[b] Estimated

Source: Dames & Moore. Environmental Report, Bear Creek Project, Converse County, Wyoming, For Rocky Mountain Energy Company. Denver, Colorado. Rocky Mountain Energy Company. 1975. p. 5-35.

## TABLE 5-38. MAJOR NOISE PRODUCING EQUIPMENT AND SOUND LEVELS FOR SURFACE MINING OPERATION (USING SCRAPERS)

| Equipment | Usage Factor[a] | Sound level at 50 feet (dBA) |
|---|---|---|
| D9G Controller tractor | .16 | 77 |
| Scraper | 1.0[b] | 87 |
| Drill | .04 | 84 |
| Air compressor | .04 | 67 |

Equivalent Sound Level: 83 dB at 100 feet

[a] Percentage of time in noisiest operating mode

[b] Estimated

Source: Dames & Moore. Environmental Report, Bear Creek Project, Converse County, Wyoming, For Rocky Mountain Energy Company. Denver, Colorado. Rocky Mountain Energy Company. 1975. p. 5-36.

### 5.4.1.3e Occupational Health and Safety

The results of a five-year survey on the occupational health hazards related to the operations of nuclear fuel cycle facilities indicate that a typical (including surface and underground) uranium mining operation has the following occupational health statistics:[1]

| | |
|---|---|
| Deaths: | 1.8 per year |
| Injuries | 69 per year |
| Man-Days Lost: | $4.28 \times 10^3$ per year |

The Mining Enforcement Safety Administration reported that no deaths and 34 non-fatal injuries occurred during surface uranium mining activity in 1976.[2]

## 5.4.2 Underground Mining

### 5.4.2.1 Technology

Underground uranium mining techniques are significantly different from underground coal mining techniques. The two major differences are related to seam sizes and mine ventilation systems. Most uranium ore bodies are long, thin, and quite erratic in occurrence, and thus require special adaptations of routine coal mining techniques. Since the seam at any one site is often quickly mined, both the working equipment and total mining operations must be highly mobile. Special ventilation systems are required in underground uranium mines because of the radon gas created by the uranium. To maintain radon radioactivity in the air at acceptable levels, large-capacity air circulation pumps are used in conjunction with special exhaust shafts at tunnel extremities to provide adequate ventilation throughout the mine Fresh air enters the main shaft, travels through the various tunnels and passageways, and exits through the vent holes.

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[1] U.S. Atomic Energy Commission. The Safety of Nuclear Power Reactors (Light Water-Cooled) and Related Facilities, Final Draft, WASH-1250. Springfield, VA. Nat'l. Tech. Inf. Service. 1973.

[2] Johns, B.D. Writer/Editor. Office of Information, Mining Enforcement Safety Administration. Information from telephone conversation. January 16, 1978.

Underground mining is normally employed to extract uranium ore bodies that are at depths greater than 400 feet.[1,2] Access to underground uranium mines can be accomplished by either the adit method, the incline method, the shaft method, or any combination of the methods.[3]

The adit method uses a horizontal access or passage to the mine and is normally used when the uranium ore deposits are near steep hills, mountains or cliffs.[4,5] It is the simplest and cheapest method of gaining access to the ore bodies. The ore is hauled out of the mine by shuttle cars, a small train, or a conveyor system.

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[1] Battelle-Columbus and Pacific Northwest Labs. Environmental Considerations in Fugure Energy Growth. Columbus, Ohio. 1973. p. 455.

[2] Klemenic, John, (U.S. Atomic Energy Commission). Examples of Overall Economics in a Future Cycle of Uranium Concentrate Production for Assumed Open Pit and Underground Mining Operations. TID-26294. Springfield, VA. NTIS. 1972.

[3] Nuclear Assurance Corp. U.S. Uranium, Economics and Technology. NAC-1. Atlanta, GA: Nuclear Assurance Corp. p. VII-1.

[4] Clark, Don A. State-of-The-Art - Uranium Mining, Milling, and Refining Industry. Rob't. S. Kerr Environmental Research Lab. EPA: Ada, OK. 1974. p. 26.

[5] Nuclear Assurance Corp., *op.cit.*

The incline method is employed when the ore deposits are at shallow depths.[1] The passage is usually inclined at an angle of 15 to 25 degrees and it proves to be more economical than the shaft method, but slightly more expensive than the adit method.[2]

Access by the shaft method is used for deep uranium ore mines. The shaft is normally a vertical passage with either a circular or a rectangular cross-section.[3] Preference for the type of shaft cross-section is dependent on the mine strata. For example, in a water-saturated formation a circular concrete shaft is preferred.[4] Generally, shafts that are at least 800 feet deep are concrete-lined.[5] In this type of access, elevators are used to lower men and equipment to the ore deposits.[6] Self-dumping buckets called "skips" are used to hoist ore out of the mine.

Underground uranium mining operations normally use either open stope, room and pillar, longwall retreat, or panel mining techniques.[7,8] For mines with narrow veins, the open stope method is best suited for the mining operation.[9] In this method, mining is accomplished by step-wise advances into the ore vein. The vein is divided into sections. Each section measuring 10 to 20 feet is mined to completion, then the operations move to the next section. Before the newly mined section is left behind, it is normally supported. The support consists of stulls and headboards, and rock bolts. As an alternative the mined out portion may be backfilled with waste material from either the mining operation itself or from the milling operation. The mining operation progresses in this manner until the entire ore vein is exhausted.

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[1] Nuclear Assurance Corp. U.S. Uranium, Economics and Technology. NAC-1. Atlanta, GA: Nuclear Assurance Corp. p. VII-1.

[2] Youngberg, Elton A. "The Uranium Industry - Exploration, Mining, and Milling," IEEE Trans. Power Appar. Syst. PAS-92 (4) 1201-8. 1973.

[3] *Ibid.*

[4] *Ibid.*

[5] Clark, Don A. State-of-the-Art - Uranium Mining, Milling, and Refining Industry. EPA 660/2-74-038. Rob't S. Kerr Environmental Research Lab. 1974.

[6] Nuclear Assurance Corp., *op.cit.*

[7] Clark, Don A., *op.cit.*

[8] Nuclear Assurance Corp., *op.cit.*

[9] *Ibid.*

For mines with considerably wider veins, the rest of the aforementioned mining techniques can be used. Rooms mined by the room and pillar method are about 20 feet wide and approximately 10 to 20 feet high.[1] During the initial phase of the mining operations, pillars of unmined material about 40 to 60 feet square are left in place to support the roof. As the mining operations reach completion in this area, these pillars are extracted upon retreat, and the roof is allowed to collapse in a controlled manner.

The panel mining method is like the room and pillar method, except that the pillars are narrower and longer. Figure 5-5 illustrates an underground uranium mining operation by the panel method.

Another mining technique employed when the mine has wide veins is the so-called longwall retreat. It was first introduced to the U.S. about 20 years ago for coal mining purposes.[2] In this method, the entire length of the vein is mined by making a series of horizontal cuts extending from one side of the vein to the other. As the mining operations progress, the roof of the

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[1] Nuclear Assurance Corp. U.S. Uranium. Economics and Technology, NAC-1. Atlanta, GA.

[2] TRW Systems Group. Underground Coal Mining in the United States. Research and Development Programs, BP 193 934. Springfield, VA: Nat'l Tech. Inf. Service. 1972.

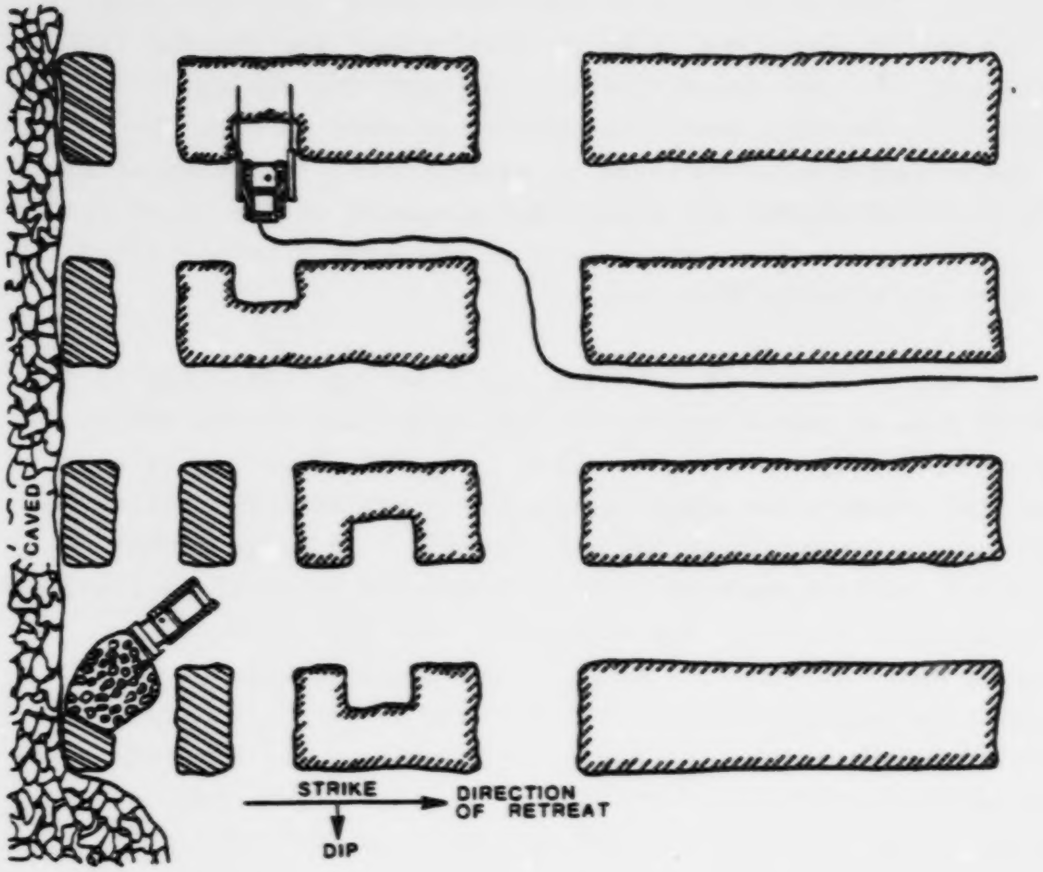
CAVED
STRIKE
DIRECTION OF RETREAT
DIP

Figure 5-5. Underground Uranium Mining, Typical Mine Layout Using Panel Method.

Source: Nuclear Assurance Corporation. U.S. Uranium Economics and Technology. Atlanta, Georgia. Nuclear Assurance Corp. NAC-1. p. VII-5.

areas that have been most recently mined are supported by a row of hydraulic jacks or retractable posts which extend the width of the cut. Upon completion of each horizontal cut, the outermost row of the hydraulic jacks or steel posts are removed from the previous cut and repositioned to support the new cut.[1] Behind the advancing working area, the roof is allowed to cave in; in some cases blasting is employed to effect this. The purpose of caving is to alleviate the overburden pressure on the other portions of the panel being mined, and at the same time to partially back fill the already mined areas.

The ore is broken by drilling and blasting. Drilling is normally done by diesel-driven or compressed air-driven drills equipped with tungsten carbide drill bits.[2,3] Blasting is accomplished by dynamite or ammonium nitrate mixed with fuel oil. The broken ore is loaded by mechanical devices. In large mining operations, mucking machines (small front end loaders) or slushers (small dragline buckets) are employed. The ore is hauled by trucks or dump cars and is taken to the access station. Here, the ore is brought to the surface by shuttle cars, rail cars, or by self-dumping buckets. The choice depends on the type of access to the mine as previously mentioned. The ore, upon reaching the surface, can be blended to a certain grade as desired by the receiving mills. The ore is then transported by trucks or by rail to the mill.[4]

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[1] Nuclear Assurance Corp. U.S. Uranium. Economics and Technology, NAC-1. Atlanta, GA.

[2] *Ibid.*

[3] Youngberg, Elton A. "The Uranium Industry - Exploration, Mining, and Milling." IEEE Trans. Power Appar. Syst. PAS-92 (4) 1201-8. 1973.

[4] Nuclear Assurance Corp., *op.cit.*

An isometric view of an underground mine that illustrates the extraction of the uranium ore is shown in Figure 5-6.[1] Figure 5-7 summarizes the material flow and effluent flow associated with underground uranium mining operations.[2]

Overburden (generally referred to as gangue) resulting from underground mining operations is about one cubic yard or less per ton of ore.[3] It is significantly less than the overburden moved in surface mining operations.

### 5.4.2.2 Input Requirements

The exemplary underground uranium ore mine chosen to represent requirements for underground mining is one that produces 1200 tons/day ore. This is equivalent to an average daily energy output of 1.12 x $10^{12}$ Btu assuming an ore grade of 0.20 percent $U_3O_8$ (0.7 percent $U^{235}$), a heating value of 71.4 x $10^{12}$ Btu per ton $U^{235}$ fissioned[4] and a recovery of 93 percent of $U_3O_8$ in the ore. The various inputs to this size facility will be discussed in the following sections.

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[1] Youngberg, Elton A. "The Uranium Industry - Exploration, Mining, and Milling." IEEE Trans. Power Appar. Syst. PAS-92 (4) 1201-8. 1973.

[2] Battelle-Columbus and Pacific Northwest Labs. Environmental Considerations in Future Energy Growth. Columbus, OH. 1973.

[3] Battelle, Pacific Northwest Labs. Data for Preliminary Demonstration Phase of the Environmental Quality Information and Planning System (EQUIPS), BNWL-B-141. Richland, WA. 1971.

[4] Pratt and Withney Aircraft. Aeronautical Vest-Pocket Handbook, 10th ed. 1964.

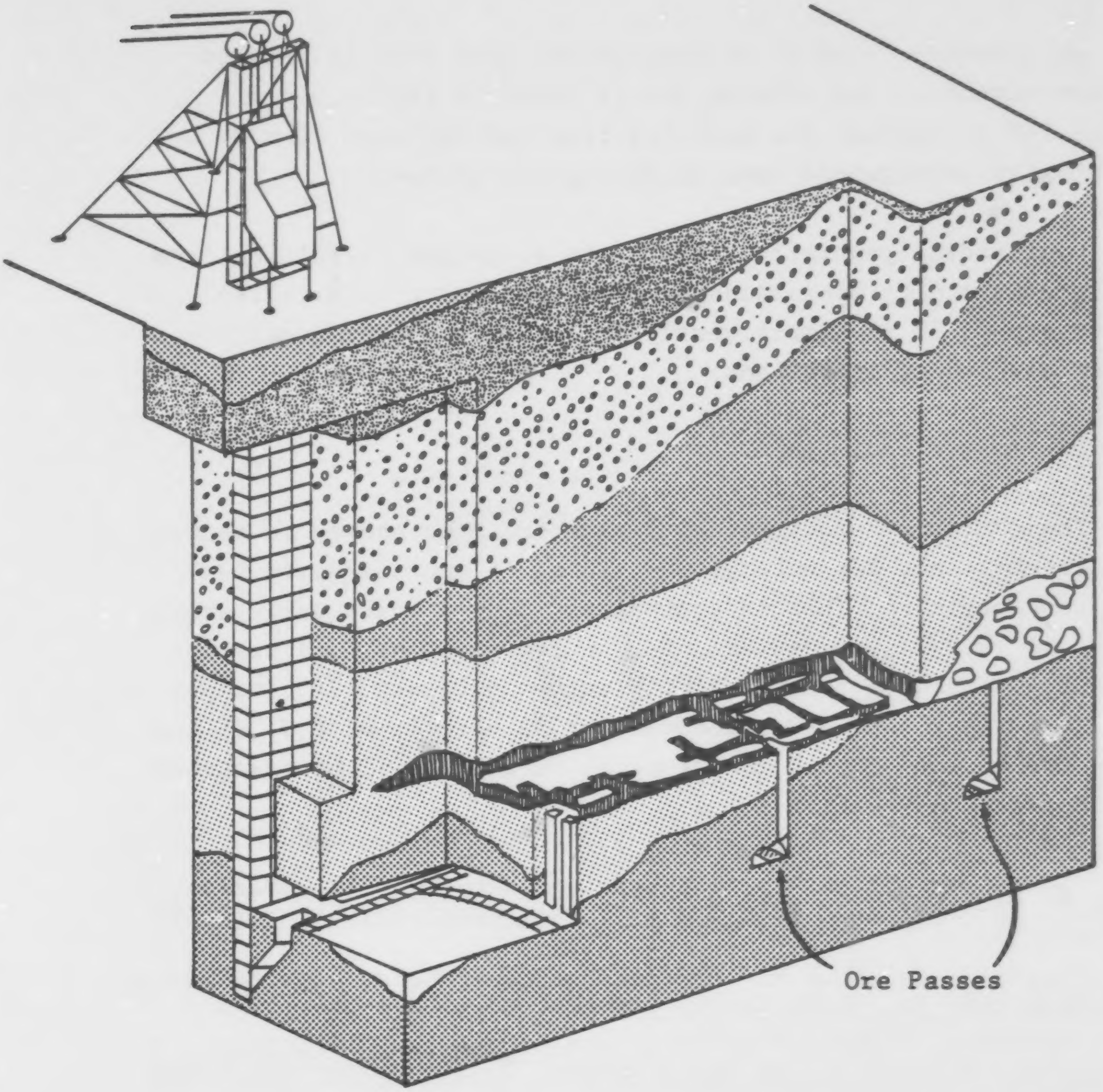

Figure 5-6. Underground Uranium Mining Operation.

Source: Youngberg, Elton A. "The Uranium Industry-Exploration, Mining, and Milling." IEEE Trans. Power Appar. Syst. Vol. PAS-92(4). (1973). p. 1205.

02-2412-1

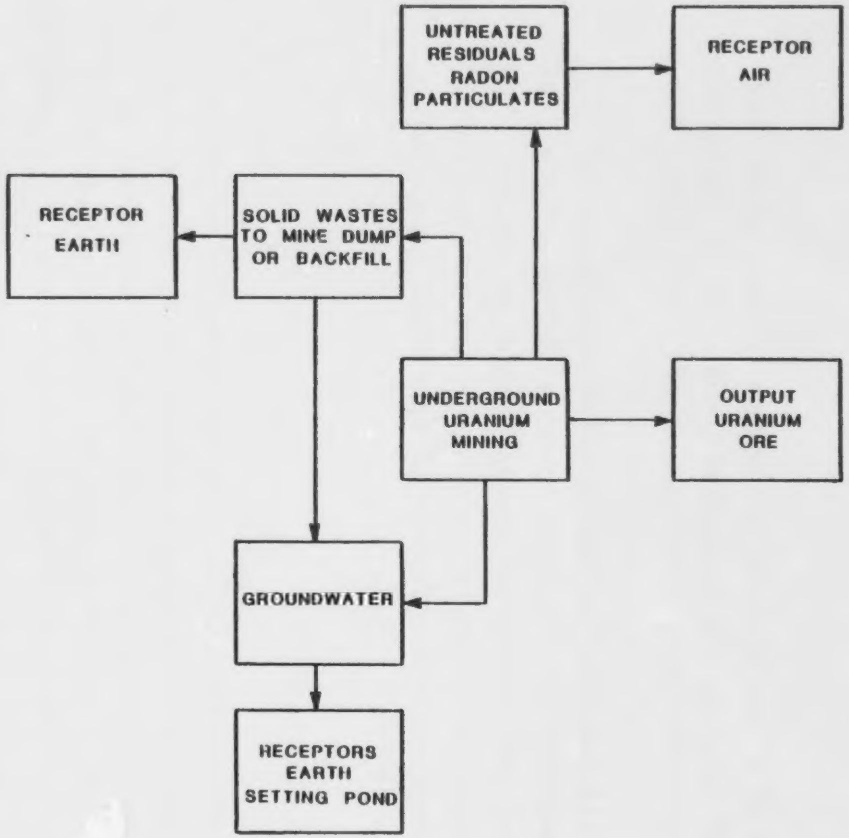
UNTREATED RESIDUALS RADON PARTICULATES
RECEPTOR AIR
RECEPTOR EARTH
SOLID WASTES TO MINE DUMP OR BACKFILL
UNDERGROUND URANIUM MINING
OUTPUT URANIUM ORE
GROUNDWATER
RECEPTORS EARTH SETTING POND

Figure 5-7. Underground Uranium Mining, Block Diagram.

Source: Battelle - Columbus and Pacific Northwest Labs. Environmental Conditions in Future Energy Growth. Columbus, Ohio. Battelle-Columbus and Pacific Northwest Labs. 1973. p. 457.

### 5.4.2.2a Manpower Requirements

Exxon has estimated the manpower requirements to construct and operate a typical underground uranium mine. The mine would produce about 1500 tons per day using either room and pillar or long wall retreat methods. The manpower requirements for a 1200 per day mine were scaled from this estimate and are presented in Tables 5-39 and 5-40.

Construction of a new mine is estimated to take about two years.[1] Table 5-39 details the 61 workers employed to construct the mining facilities (buildings, shafts, roads, utilities, etc.).

Each mine would require 197 workers for nine years of operation.[2] The majority of the work force would be miners (102) but 95 other skilled and unskilled workers would be needed. The normal work week would be 40 hours, with each day divided into shifts. Only approximately one-fourth of the total personnel would be working at any one time.

### 5.4.2.2b Materials and Equipment

Although no data were available on the quantity of materials required to construct an underground uranium mine, Bechtel Corporation has estimated the materials required to construct an underground coal mine.[3] Assuming that the materials used for construction of a coal mine are similar to those used in a uranium mine, and that the amount of material varies linearly with mine

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[1] Planning Support Group, Bureau of Indian Affairs. Uranium Exploration, Mining and Milling Proposal, Navajo Indian Reservation, New Mexico. Volume I. Billings, MT: Bureau of Indian Affairs, Department of the Interior. June, 1976. p. I-39.

[2] *Ibid*, p. I-37.

[3] Carasso, M., *et al*. Energy Supply Model, Computer Tape. San Francisco, Bechtel. 1975.

## TABLE 5-39. MANPOWER REQUIREMENT FOR CONSTRUCTION OF A 1200 TON/DAY UNDERGROUND URANIUM MINE

| Construction Activity and Skill | Number |
|---|---|
| Roads and Utilities | |
| Supervisors | 2 |
| Operating engineers | 5 |
| Electricians | 4 |
| Laborers | 2 |
| Construction of Surface Facilities and Mine Development | |
| Supervisors and staff | 8 |
| Foremen | 4 |
| Miners | 10 |
| Hoistmen | 2 |
| Mechanics | 7 |
| Skilled laborers | 14 |
| Carpenters | 1 |
| Operating engineers | 2 |

Source: Planning Support Group, Bureau of Indian Affairs. Uranium Exploration, Mining and Milling Proposal, Navajo Indian Reservation, New Mexico. Volume I. Billings, MT: Bureau of Indian Affairs, Department of the Interior. June, 1976. p. 1.5.

## TABLE 5-40. MANPOWER REQUIREMENT FOR OPERATION OF A 1200 TON/DAY UNDERGROUND URANIUM MINE

| Skill | Number* |
|---|---|
| Staff and supervisors | 19 |
| Foremen | 6 |
| Hoistmen | 3 |
| Mechanics | 13 |
| Carpenters | 3 |
| Miners | 102 |
| Laborers | 51 |

*Approximately one-fourth of the total personnel would be working at any one time.

Source: Planning Support Group, Bureau of Indian Affairs. Uranium Exploration, Mining and Milling Proposal, Navajo Indian Reservation, New Mexico. Volume I. Billings, Montana: Bureau of Indian Affairs, Department of the Interior. June, 1976. p. 1.6.

capacity, the material requirements for an underground uranium mine can be calculated. The material requirements for the 1200 ton/day uranium underground mine would then be 27,000 tons of concrete, 1350 tons of pipe and tubing, 1750 tons of structural steel, and 2000 tons of reinforcing bars.

Exxon has estimated the equipment requirements for operating an underground uranium mine. These requirements are listed in Table 5-41, but the numbers have been scaled linearly to reflect operation of a 1200 ton/day mine.

### 5.4.2.2c Economics

In 1972 the U.S. Atomic Energy Commission issued a report on the estimated costs for uranium mining and milling.[1] Economic data were given for a 2000 ton/day underground mine and mill representing costs as of January 1, 1972. The information provided in Table 5-42 presents this information scaled to a 1200 ton/day mine and representing costs in 1975 dollars. Costs were adjusted by using percent of total cost calculated from the AEC data and total costs from a Dames and Moore report.[2] The costs for a 1200 ton/day mine were interpolated from derived costs for mines of 500, 1000, and 2000 ton/day capacity.

The effect of mine depth on capital and operating costs was also presented for three sizes of underground mines in the Dames and Moore report.[3] This information was used to determine the

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[1] Klemenic, John, (U.S. Atomic Energy Commission). Examples of Overall Economics in a Future Cycle of Uranium Concentrate Production for Assumed Open Pit and Underground Mining Operations. TID-26294. Springfield, VA: NTIS. 1972.

[2] Lootens, D.J. Uranium Production Methods and Economic Considerations. Park Ridge, Illinois. Dames and Moore. 1975.

[3] *Ibid.*

## TABLE 5-41. TYPICAL EQUIPMENT REQUIRED FOR A 1200 TON/DAY UNDERGROUND URANIUM MINE

| | Number |
|---|---|
| Surface Plant Equipment Required | |
| Service hoist, 400 HP, electric | 1 |
| Production hoist, 500 HP, electric | 1 |
| Compressor plant, 1,200 HP, electric | 1 |
| Emergency electric generator, 3,000 kva, diesel | 1 |
| Ventilation system, 1,000 HP, electric | 1 |
| Heating system, 14 million Btu/hr, natural gas | 1 |
| Portable concrete batch plant | 1 |
| Transportation and Service Vehicles Equipment Required | |
| Ore hauler, 50-ton, diesel | 1 |
| Service vehicles, 3/4-ton, gasoline | 4 |
| Forklift, 4,000-lb, gasoline | 1 |
| Underground Mining Equipment Required | |
| Continuous miner, electric | 4 |
| Haulage motors, track-type, 10-ton, diesel | 2 |
| Ore cars, 110 cu ft | 10 |
| Slushers, 30-75 HP, electric and pneumatic | 5 |
| Raise boring machine, electric | 1 |
| Load-haul-dump vehicle, 2 cu yd, diesel | 8 |
| Utility hoist, pneumatic | 3 |
| Drills, pneumatic | 4 |
| Pumps, electric | 10 |

Source: Planning Support Group, Bureau of Indian Affairs. Uranium Exploration, Mining and Milling Proposal, Navajo Indian Reservation, New Mexico. Volume I. Billings, MT: Bureau of Indian Affairs, Department of the Interior. June, 1976. p. 1.3, 1.4.

TABLE 5-42. ESTIMATED COSTS FOR URANIUM CONCENTRATE (YELLOWCAKE) PRODUCTION AT AN UNDERGROUND MINE PRODUCING 1200 TONS/DAY OF ORE CONTAINING 0.25 PERCENT $U_3O_8$ (1975 DOLLARS)

| Costs | |
|---|---|
| Capital | $10^3$ DOLLARS |
| Acquisition | 2,110 |
| Exploratory Drilling | 7,630 |
| Development Drilling | 3,510 |
| Mine Primary Development | 7,730 |
| Mine Plant and Equipment | 1,550 |
| Mill Construction | 4,500 |
| TOTAL CAPITAL | 26,430 |
| Operating | $/Ton |
| Mining | 16.45 |
| Hauling | 1.20 |
| Milling | 5.98 |
| Royalty | 2.62 |
| TOTAL OPERATING | 26.25 |

Source: Kelmenic, John (U.S. Atomic Energy Commission). Examples of overall economics in a future cycle of uranium concentrate production for assumed open pit and underground mining operations, TID-26294, Springfield, VA: NTIS, 1972, p. 7.

effect of mine depth on a 1200 ton/day mine. The costs were interpolated from costs for mine sizes of 500, 1000, and 2000 ton/day. The capital and operating costs for a 1200 ton/day mine are shown in Table 5-43 for two different mine depths.

TABLE 5-43. CAPITAL AND OPERATING COSTS ESTIMATE FOR HYPOTHETICAL URANIUM UNDERGROUND MINE AND MILL (1975 DOLLARS) 1200 TON/DAY CAPACITY

| Mine Depth | Capital Costs ($10^3$ Dollars) | Operating Costs ($/Ton) |
|---|---|---|
| 2000 feet deep | 23,800 | 26.61 |
| 4000 feet deep | 37,500 | 30.60 |

Source: Lootens, D.J. Uranium Production Methods and Economic Considerations. Park Ridge, Illinois: Danes & Moore, 1975.

### 5.4.2.2d Water Requirements

Major water requirements for an underground uranium mine result from the need for dust suppression in the mine and potable water requirements. The water for dust suppression is provided by water intrusion in the mine from surrounding aquifers. The potable water requirements for the mine office, shop, and showers would be provided by water wells. Potable water requirements are estimated to be about 20,000 gallons per day for a 1500 ton/day mine.[1] Assuming these water requirements are proportional to manpower requirements, the estimated potable water requirements for a 1200 ton/day underground mine would be approximately 16,000 gallons per day.

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[1] Planning Support Group, Bureau of Indian Affairs. Uranium Exploration, Mining and Milling Proposal, Navajo Indian Reservation, New Mexico. Volume I. Billings, MT: Bureau of Indian Affairs, Department of the Interior. June, 1976. p. 1.4.

### 5.4.2.2e Land Requirements

Exxon has estimated that a 1500 tons per day underground uranium mine would require about 10 acres of surface land.[1] This would not include the land required for ore haulage roads between the mine and a mill. Based on Exxon's estimates a 1200 ton/day mine underground uranium mine will require a surface area of about 8 acres.

### 5.4.2.2f Ancillary Energy

Energy requirements for an underground mine result from the need for electric power for lighting, ventilation, and equipment, natural gas for space heating, and hydrocarbon fuels for mining equipment. Exxon has estimated an electric power requirement of 4000 kva for a 1500 ton/day mine.[2] This would be equivalent to about 3500 kw of three phase electric power. From a ratio of mine sized this requirement was calculated to be 2800 kw for a 1200 ton/day mine. Exxon also estimated a natural gas requirement of up to 14,000 standard cubic feet per hour for mine heating.[3] A heating value of 1000 Btu/cubic feet[4] gives this requirement the energy equivalence of $14 \times 10^6$ Btu/hr. This requirement becomes $11 \times 10^6$ Btu/hr when ratioed by mine size down to a 1200 ton/day mine. Liquid hydrocarbon fuel usage for a 1500 ton/day underground mine would be about 150,000 gallons/year.[5] If this is assumed to be diesel fuel with a heating value of $0.139 \times 10^6$ Btu/gal,[1] the energy represented in the fuel would be about $20.9 \times 10^9$ Btu/year. This requirement would be approximately $17 \times 10^9$ Btu/year when ratioed to a 1200 ton/day mine size.

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[1] Planning Support Group, Bureau of Indian Affairs. Uranium Exploration, Mining and Milling Proposal, Navajo Indian Reservation, New Mexico. Volume I. Billings, MT: Bureau of Indian Affairs, Department of the Interior. June, 1976. p. III-3.

[2] *Ibid.*, p. 1.4.

[3] *Ibid.*, p. 1.4.

[4] Battelle Columbus Laboratories. Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing (Phase 5--Energy Data and Flowsheets, Intermediate-Priority Commodities). Columbus, OH: Battelle Columbus Laboratories. September 16, 1975. p. A-1.

[5] Planning Support Group, Bureau of Indian Affairs, *op.cit.* p. 1.4.

### 5.4.2.3 Outputs

Outputs from an underground uranium ore mine are discussed in the following sections. These ouputs are: air emissions, water effluents, solid waste, noise pollution, and occupational health and safety statistics.

The mine is assumed to be in steady-state operation. This means that the shafts have been drilled and the mine is producing ore on a regular basis.

#### 5.4.2.3a Air Emissions

Underground uranium mining operations produce dust in the mine tunnels and crosscuts. Radon gas and its daughters are emitted from the exposed surfaces in the mine and present an even greater concern than the dust. The dust and radionuclides generated by the mining process are emitted to the atmosphere through exhaust ventillation shafts. About 150 cfm/ton[2] (180,000 cfm for a 1200 ton/day mine) of air is circulated through the mine to maintain a reasonably healthy atmosphere for the miners. This air flow dilutes the pollutants to a concentration well within the Federal and State regulatory standards.[3] The velocity of the air emerging from the vent shafts would cause the pollutants to be rapidly dispersed into the atmosphere. An estimate given for the maximum average concentration of radon-222 in the mine vent exhausts is $4 \times 10^{-7} \mu$ Ci/Ml.[1] This value is probably high but is the best estimate available. With a 180,000 cfm volumetric flow rate, the estimated maximum average radon-222 emission rate would be 2.94 Ci/day.

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[1] Battelle Columbus Laboratories. Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing (Phase 5--Energy Data and Flowsheets, Intermediate-Priority Commodities). Columbus, OH: Battelle Columbus Laboratories. September 16, 1975. p. A-1.

[2] Planning Support Group, Bureau of Indian Affairs. Uranium Exploration, Mining and Milling Proposal, Navajo Indian Reservation, New Mexico. Volume I, Billings, MT: Bureau of Indian Affairs, Dept. of the Interior, June 1976, p. III-8.

[3] *Ibid.*

Exxon has applied the EPA emission factors for heavy-duty diesel-powered vehicles to the estimated 150,000 gallons of liquid hydrocarbon fuels consumed per year in a 1500 ton/day mine. The estimated air pollutants produced by the 365-day operation of underground mining equipment for a 1200 ton/day mine are given in Table 5-44. These estimates were determined by reducing the emissions by a factor equal to the ratio of mine sizes. An estimate can be made of $CO_2$ emissions by assuming that all the carbon in the fuel for a 1200 ton/day mine (120,000 gallons/year of No. 2 fuel oil) is converted to $CO_2$. With a fuel composition of 87 percent carbon by weight and a density of 7.0 lb/gal, the $CO_2$ emissions would be about 300 lb/hr.

### 5.4.2.3b Water Effluents

Water effluents from an underground mine result from the intrusion water which is pumped from the mine to keep it dry. Exxon has estimated that 3000 gallons per minute would be a reasonable yield of water from an underground mine in New Mexico.[2] This water would be treated in the same way as water from a

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[1] Tennessee Valley Authority. Draft Environmental Statement, Marlin Ranch Uranium Mining. Chattanooga, Tenn.: Tennessee Valley Authority, Div. of Environmental Planning. 1975. pp. 4.6-9.

[2] Planning Support Group, Bureau of Indian Affairs. Uranium Exploration, Mining and Milling Proposal, Navajo Indian Reservation, New Mexico. Volume I, Billings, Montana: Bureau of Indian Affairs, Dept. of the Interior. June 1976. p. III-32.

TABLE 5-44. ESTIMATED AIR POLLUTANT EMISSIONS FROM ORE HAULING EQUIPMENT (1200 ton/day underground mine)

| Pollutant | Emissions lbs/day |
|---|---|
| Particulates | 4.2 |
| Sulfur Oxides | 8.9 |
| Carbon Monoxide | 73.8 |
| Hydrocarbons | 12.1 |
| Nitrogen Oxides | 120.1 |
| Aldehydes | 1.0 |
| Organic Acids | 1.0 |

Source: Planning Support Group, Bureau of Indian Affairs. Uranium Exploration, Mining and Milling Proposal, Navajo Indian Reservation, New Mexico, Volume I, Billings, Montana: Bureau of Indian Affairs, Dept. of the Interior, June 1976. p. III-9.

surface mine. Depending upon circumstances, the water may contain sufficient mining-induced contaminants to require treatment before release to the surface water. The water from the mine will probably have a total dissolved solids content of less than 1000 milligrams per litre and a pH range from 6.5 to 9.0, with the higher values more likely.[1] Contaminants in the water can include radon gas and isotopes of such elements as polonium, lead, and bismuth.

### 5.4.2.3c Solid Wastes

The solid waste generated by underground mining is much less than that for open pit mining. One cubic yard or less of waste rock is produced per ton of ore.[2] Exxon has estimated that the waste brought to the surface from an underground mine could be stored in about a five-acre area.[3] The waste would be covered with topsoil and planted with grasses and shrubs for reclamation. In cases where underground wastes are toxic, and not suitable for revegetation, they can be disposed of in abandoned portions of the mine.

### 5.4.2.3d Noise Pollution

The major sources of surface noise to environment in underground mining are the stationary equipment at the mine surface facilities. This equipment includes the blowers which supply ventilating air to the mine, together with their drive motors, and gas fired air heaters.[1] The major noise-producing equipment for an underground mine are listed in Table 5-45. The estimated values of sound power rating are in units of acoustical power. Noise levels are expected to decrease from 65 dB(A) at a radius of about 500 ft to 37 dB(A) at a radius of about 5000 ft from the mine.[2]

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[1] Planning Support Group, Bureau of Indian Affairs. Uranium Exploration Mining and Milling Proposal, Navajo Indian Reservation, New Mexico. Volume I, Billings, Montana: Bureau of Indian Affairs, Dept. of the Interior, June 1976, p. III-34.

[2] Battelle Columbus Laboratories. Environmental Considerations in Future Energy Growth. Columbus, Ohio: Battelle Columbus Laboratories, 1973, p. 458.

[3] Planning Support Group, Bureau of Indian Affairs, *op.cit.*, p. I-34.

### 5.4.2.3e Occupational Health and Safety

Accidents which occur in underground mines are caused by faulty operation of equipment, blasting mishaps, cave-ins, fire and other lesser reasons.[3] Fires are particularly dangerous since they may produce noxious gases in addition to damage from the fire itself. The 1976 injury and death statistics for uranium underground miners as reported by the Mining Enforcement Safety Administration for a 1200 ton/day underground mine are 1 death and 25 nonfatal injuries.[4]

A unique hazard to uranium miners is the exposure to radon gas and its decay products. These products would be isotopes of such elements as polonium, lead, and bismuth.[5] The products attach themselves to dust and aerosol particles in the air and if inhaled can cause lung cancer.[6]

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[1] Planning Support Group, Bureau of Indian Affairs. Uranium Exploration, Mining and Milling Proposal, Navajo Indian Reservation, New Mexico. Volume I, Billings, Montana: Bureau of Indian Affairs, Dept. of the Interior. June 1976. p. III-24.

[2] *Ibid.*, p. III-23.

[3] Johns, R.D. Writer/Editor. Office of Information, Mining Enforcement Safety Administration. Information from telephone conversation. January 16, 1978.

[4] Planning Support Group, Bureau of Indian Affairs, *op.cit.*, p. III-45.

[5] *Ibid.*, p. III-47.

[6] *Ibid.*

TABLE 5-45. NOISE-PRODUCING POTENTIAL OF SURFACE EQUIPMENT ASSOCIATED WITH AN UNDERGROUND MINE - OCTAVE BAND SOUND POWER-WATTS x $10^{-2}$

| Item (2 of each required) | Octave Band Center Frequency, Hz | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 31 | 64 | 125 | 250 | 500 | 1000 | 2000 | 4000 | 8000 |
| Vent blower | 1.0 | 20.0 | 31.6 | 39.8 | 39.8 | 3.16 | 7.9 | 0.50 | 0.039 |
| Blower motor | 35.6 | 142.0 | 7.16 | 1.42 | 0.716 | 0.716 | 0.716 | 0.716 | 0.716 |
| Gas heater | 316.0 | 100.0 | 25.1 | 100.0 | 158.0 | 79.0 | 3.16 | 1.26 | 0.126 |
| Compressor | 15.8 | 6.31 | 2.51 | 1.00 | 0.501 | 0.251 | 0.158 | 0.158 | 0.158 |

Source: Planning Support Group, Bureau of Indian Affairs. Uranium Exploration, Mining and Milling Proposal, Navajo Indian Reservation, New Mexico, Volume I, Billings, Montana: Bureau of Indian Affairs, Dept. of the Interior, June, 1976. p. III-22.

### 5.4.3 In-Situ Mining

The techniques used for in-situ solution mining of uranium involve the leaching of the uranium from underground ore deposits. This is accomplished by pumping a leaching solution into the ore through patterns of injection wells. The leaching solution dissolves the uranium and is pumped out of the ground by production wells to a processing mill. The processing mill will be discussed along with the mining process in this section as it is usually constructed as an integral part of the in-situ solution mining operation.[1,2,3]

#### 5.4.3.1 Technology

Mine Site Selection

In-situ solution mining techniques are used in situations where the uranium ore is of such a low grade that it is not economical to mine by other means or where the ore formation lies in the ground in a way to make it inaccessable by other mining techniques. The cross-section of a typical uranium ore formation is shown in Figure 5-8.[4] However, before in-situ solution mining techniques can be used the ore formation must meet certain geological requirements.

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[1] Wyoming Mineral Corporation, Exploration and Mining Division. Environmental Report, Irigary Project, Johnson County, Wyoming. Lakewood, Colo.: Wyoming Mineral Corporation, 1977, p. 10.

[2] Anderson, J. S. and M. I. Ritchie. "Solution Mining of Uranium." Mining Congress Journal, Vol. 54 (January 1968), pp. 20-23.

[3] White, L. "In-Situ Leaching Opens New Uranium Reserves in Texas." Engineering and Mining Journal, Vol. 176 (July 1975), pp. 73-80.

[4] Shock, D. A. and F. R. Conley. "Solution Mining - Its Promise and Its Problems," Proceedings from Solution Mining Symp., AIME Annual Meeting. Dallas, Tex., February 25-27, 1974, pp. 79-97.

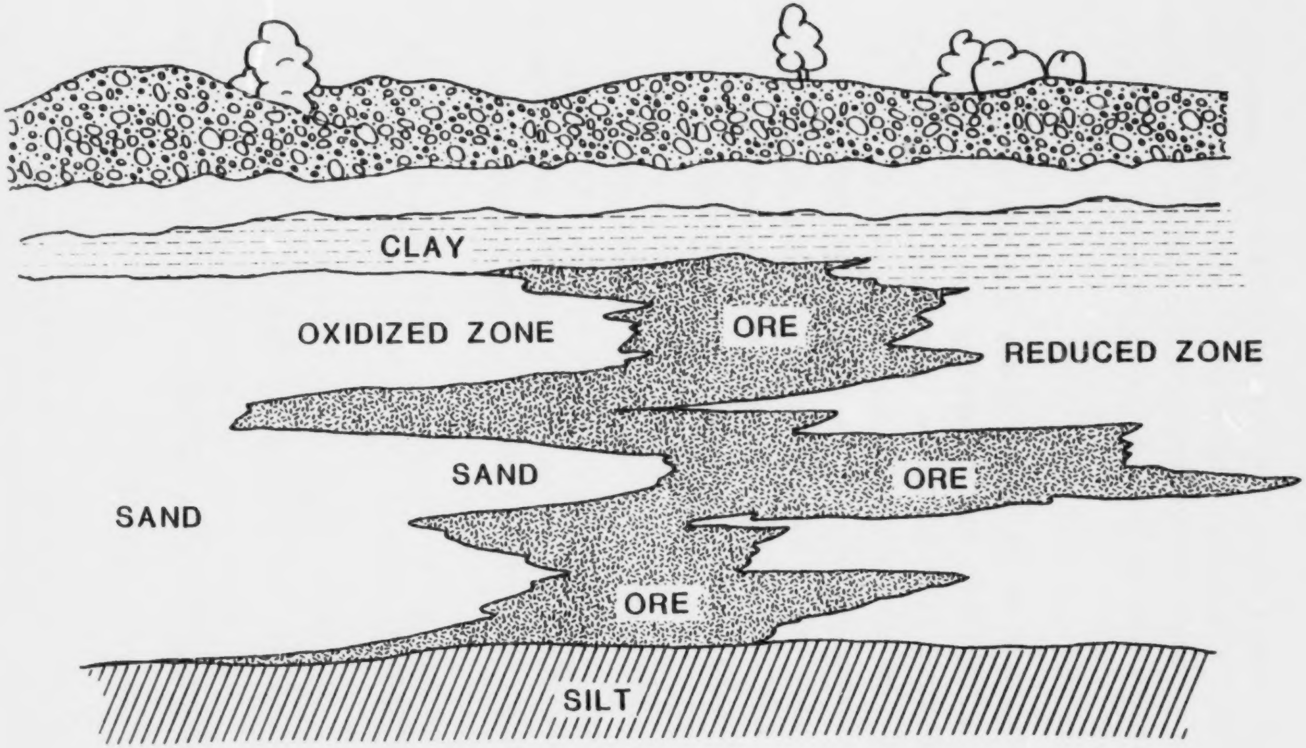
CLAY
OXIDIZED ZONE
ORE
REDUCED ZONE
SAND
ORE
SAND
ORE
SILT

Figure 5-8. Typical Uranium Ore Formation

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Source: Shock, D. A. and F. R. Conley. "Solution Mining - Its Promise and Its Problems", Proceedings from Solution Mining Symp., AIME Annual Meeting. Dallas, Texas, Feb. 25-27, 1974, p. 86.

The major requirements are that the ore formation be chemically amenable to leaching techniques, the formation be confined by natural or artificial means to restrict dilution or fluid losses and that the formation not be located in an aquifer used for a domestic water supply.[1,2,3]

If the ore formation to be mined meets all of the above requirements, then a detailed field testing program in the general area of the mine site would be initiated. A regional hydrology survey of the area surrounding the mine site and a more detailed land hydrology survey in about a 10,000-foot radius at the mine site would be made to determine ground water characteristics.[4] Additionally, a geophysical survey and a detailed program of water sampling would be performed.[5]

The results of the above testing being satisfactory, a pilot plant test program at the site would begin. Testing would be done to determine the permeability of the ore formation and the type and dimensions of the well pattern to be used.[6]

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[1] Anderson, J. S. and M. I. Ritchie. "Solution Mining of Uranium." Mining Congress Journal, Vol. 54 (January 1968), pp. 20-23.

[2] Hunkin, G. G. "A Review of In-Situ Leaching," Paper at the AIME Annual Meeting, Soc. of Mining Eng. New York: AIME Preprint 71-AS-88, February 26 - March 4, 1971. pp. 11-12.

[3] Frank, J. N. "Cost Model for Solution Mining of Uranium," Presented at the Uranium Industry Seminar. Grand Junction, Colo.: October 19-20, 1976, p. 3.

[4] Hunkin, G. G., *op.cit.*, p. 12.

[5] *Ibid.*

[6] Shock, D. A. and F. R. Conley. "Solution Mining - Its Promise and Its Problems," Proceedings from Solution Mining Symp., AIME Annual Meeting. Dallas, Tex., February 25-27, 1974, pp. 79-97.

## Well Pattern Design

In the design of a well pattern, the well spacing and location, rates of flow, and fluid pressures are all engineered to provide the solution confinement, sweep efficiency, and leach contact time required for maximum productivity.[1] If the ground-water flow is significantly greater than the proposed leaching solution flowrate, then the injection wells would be located upstream from the production well to provide an efficient sweep (area of contact) of the ore formation containing the uranium. However, in most cases the ground-water flow is very small. In such cases a well pattern consisting of a production well surrounded by a perimeter of injection wells, or, a pattern of an injection well surrounded by a perimeter of production wells is chosen. The contacted area of the ore formation is controlled by the hydraulic gradients imposed within the formation. The gradients are imposed by the injection well pressures and volumes in conjunction with the amount of flow from the production well.[2] Three different well patterns are shown in Figure 5-9.[3,4,5] Figure 5-10 is a cross-sectional view of how the wells would be placed into the ore formation.[6]

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[1] Hunkin, G. G. "The Environmental Impact of Solution Mining for Uranium." Mining Congress Journal, Vol. 61 (October 1975), pp. 24-27.

[2] *Ibid.*

[3] Anderson, J. S. and M. I. Ritchie. "Solution Mining of Uranium." Mining Congress Journal, Vol. 54 (January 1968), pp. 20-23.

[4] Wyoming Mineral Corporation, Exploration and Mining Division. Environmental Report, Irigary Project, Johnson County, Wyoming. Lakewood, Colo.: Wyoming Mineral Corporation, 1977.

[5] Humble Oil and Refining Company. Applicants Environmental Report - Proposed Uranium In-Situ Mining Test, Converse County, Wyoming. Houston, Tex.: Humble Oil and Refining Co., September 1970.

[6] Wyoming Mineral Corporation, Exploration and Mining Division, *op.cit.*, p. 7.

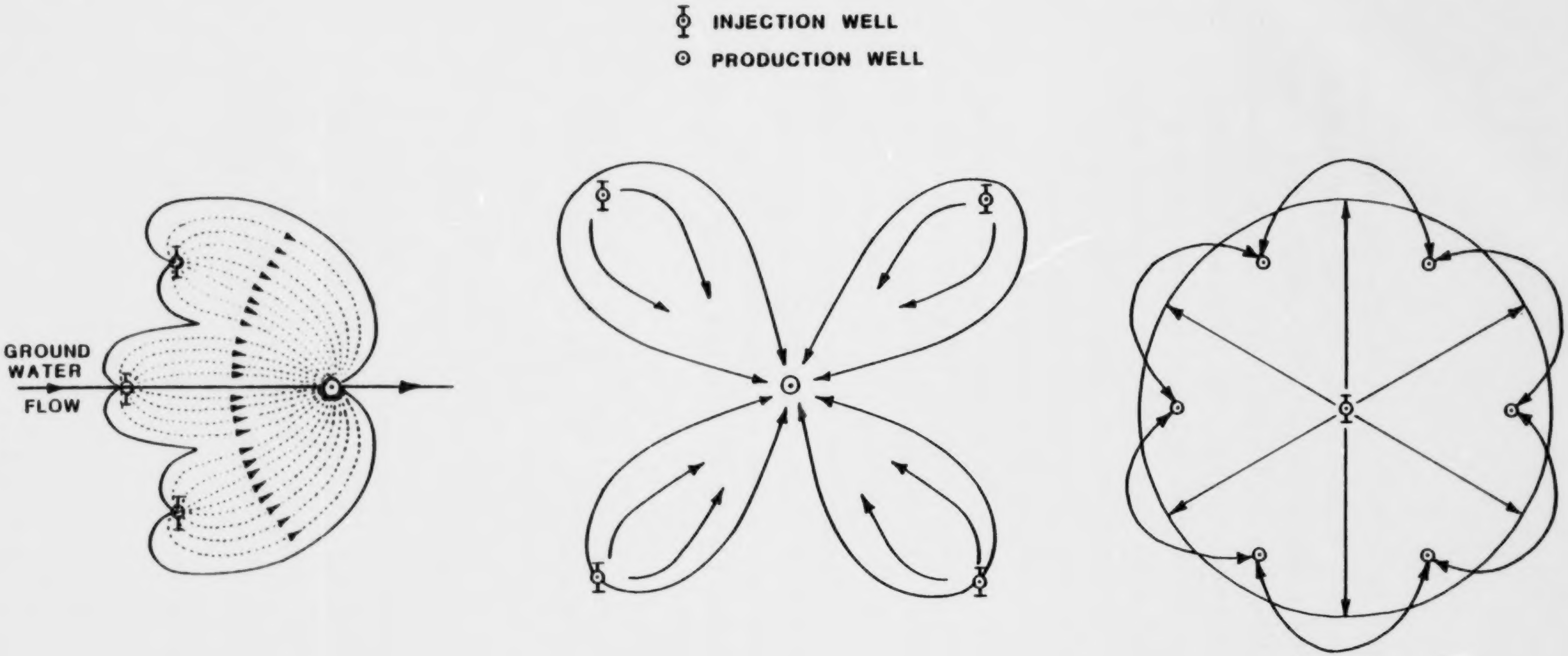

Figure 5-9. In-Situ Solution Mining Well Patterns

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Sources: Anderson, J. S. and M. I. Ritchie. "Solution Mining of Uranium." Mining Congress Journal, Vol. 54 (January 1968), pp. 20-23.

Wyoming Mineral Corporation, Exploration and Mining Division. Environmental Report, Irigary Project, Johnson County, Wyoming. Lakewood, Colo.: Wyoming Mineral Corporation, 1977, p. 9.

Humble Oil and Refining Company, Applicants Environmental Report - Proposed Uranium In-Situ Mining Test, Converse County, Wyoming. Houston, Texas: Humble Oil and Refining Co., September 1970.

02-2327

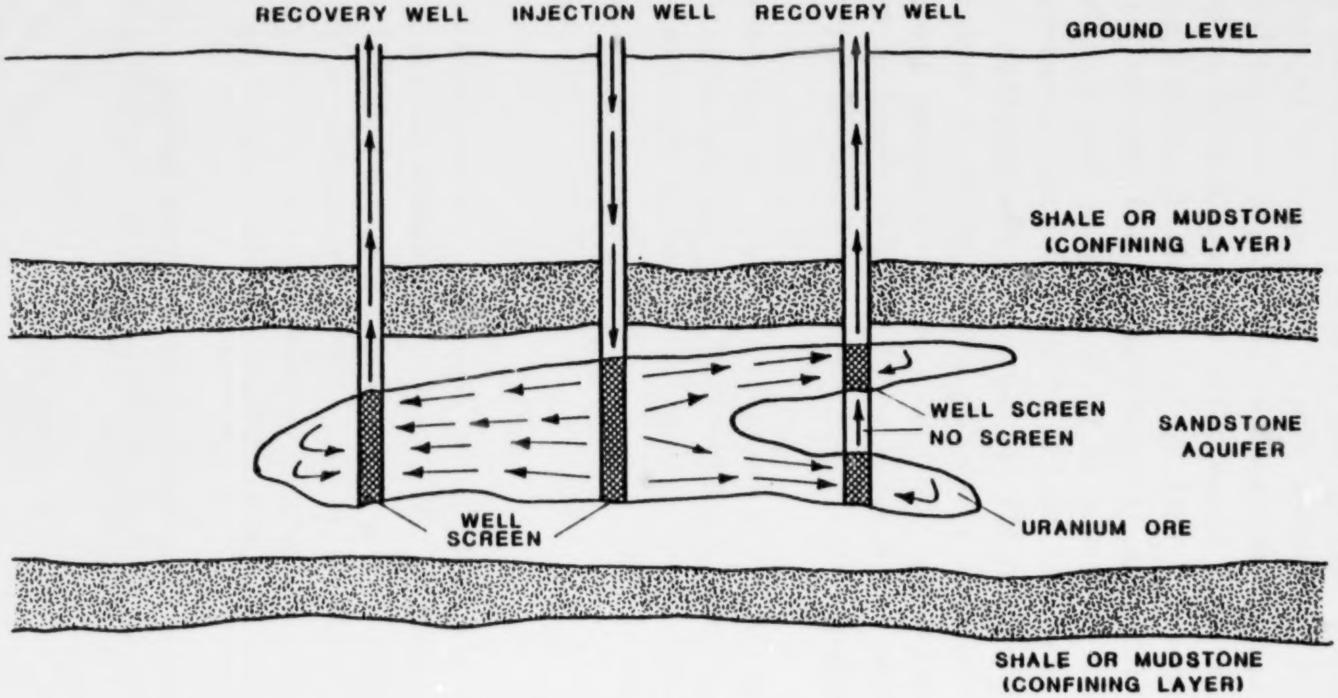
RECOVERY WELL
INJECTION WELL
RECOVERY WELL
GROUND LEVEL
SHALE OR MUDSTONE (CONFINING LAYER)
WELL SCREEN
NO SCREEN
SANDSTONE AQUIFER
WELL SCREEN
URANIUM ORE
SHALE OR MUDSTONE (CONFINING LAYER)

Figure 5-10. Solution Mining Wells Positioned in Ore Formation

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Source: Wyoming Mineral Corporation, Exploration and Mining Division. Environmental Report, Irigary Project, Johnson County, Wyoming. Lakewood, Colo.: Wyoming Mineral Corporation, Corporation, 1977, p. 7.

The pattern of production and injection wells makes up what is sometimes referred to as a uranium production cell. The size of these cells varies from as few as 2 wells for a pilot plant to 5 or 7 wells for a commercial plant. Each cell is independent from another. They are designed so that there is no fluid flow across cell boundaries. These cells are combined to cover the ore formation and comprise a well field. A well field designed to support a production rate of approximately 125,000 lbs $U_3O_8$ per year would typically contain 10 to 15 cells.[1] The total mine unit would utilize 4 to 6 well fields at any one time to maintain an annual production of 500,000 lbs $U_3O_8$. As the solution from the production cells reaches a uranium content which is uneconomical to process, the cells are shut off and new cells are brought on line. This process is repeated until the well field is mined completely. A typical well field layout is shown in Figure 5-11.[2]

Monitoring wells are also located around the perimeter of the ore body to monitor the groundwater quality in the vacinity of the operation. These wells are essential to insure that there is no groundwater contamination.

## Leaching Solutions

In addition to the well field design, the leaching solution to be used is determined for a particular mine location. There are two major considerations in selecting a leaching solution for uranium solution mining. First, it must be capable of oxidizing the uranium and then forming a soluble uranium complex which can be recovered in the processing plant. Second, reactions with the

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[1] Wyoming Mineral Corporation, Exploration and Mining Division. Environmental Report, Irigary Project, Johnson County, Wyoming. Lakewood, Colo.: Wyoming Mineral Corporation. 1977. p. 27.

[2] *Ibid.*, p. 25.

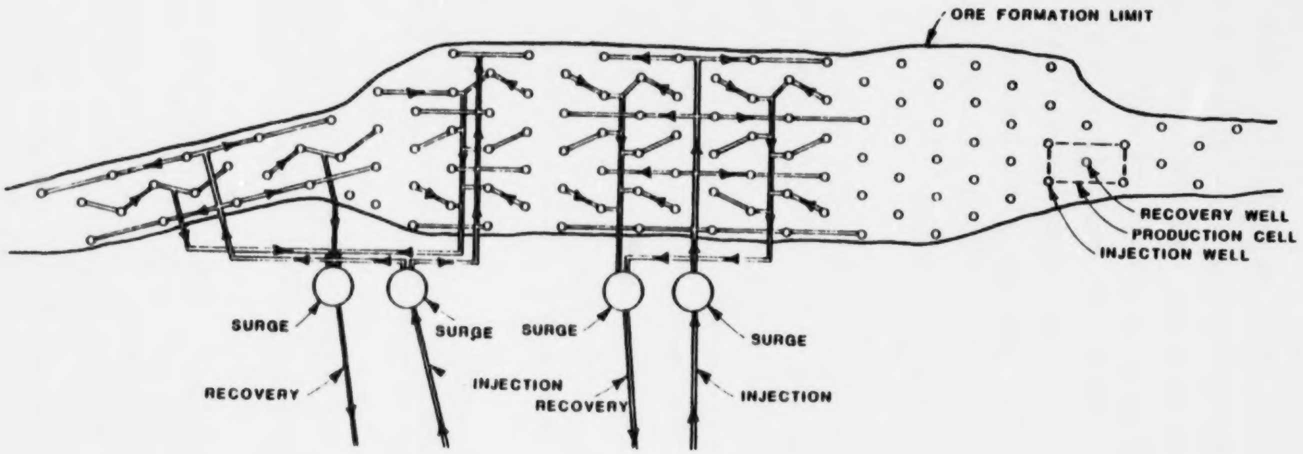
ORE FORMATION LIMIT
RECOVERY WELL
PRODUCTION CELL
INJECTION WELL
SURGE
SURGE
SURGE
SURGE
RECOVERY
INJECTION
RECOVERY
INJECTION

Figure 5-11. Typical Well Field Layout (Aerial View)

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Source: Wyoming Mineral Corporation Exploration and Mining Division. Environmental Report, Irigary Project, Johnson County, Wyoming. Lakewood, Colo.: Wyoming Mineral Corporation, 1977, p. 25.

minerals present in the formation (*i.e.*, calcite, clays, feldspars, zeolites, pyrites and carbonaceous materials) should be minimal.[1] Both chemical reactions, and physical or chemical sorption may occur between the leaching solution and the ore formation. Alterations of the leaching solution composition and/or mobilization of contaminants may result from such reactions and later impede aquifer restoration. Two ions are commonly used in uranium solution mining to form a soluble complex with the oxidized uranium. The sulfate ion is used in the acid leach process and the bicarbonate ion in the alkaline leach process.[2,3,4,5,6]

The stronger action of the sulfuric acid leach allows better recoveries (85-95%) of uranium to be obtained, and oxidation of the uranium is easily accomplished with a variety of chemical oxidants.[7] However, the acid leach system tends to be limited by the side reactions of the leaching solution. These reactions involve the attack and breakdown of minerals naturally occurring in the uranium ore deposit. In addition, the leaching essentially stops when the pH of the leaching solution increases above 2.

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[1] Wyoming Mineral Corporation, Exploration and Mining Division. Environmental Report, Irigary Project, Johnson County, Wyoming. Lakewood, Colo.: Wyoming Mineral Corporation. 1977. p. 104.

[2] *Ibid.*

[3] Exxon Company, U.S.A. Application for Amendment to Source Material License SUA-1139 for Solution Mining of Uranium, Supplemental Environmental Report. Houston, TX: Exxon Company. 1977. p. 10-2.

[4] Anderson, J.S. and M.I. Ritchie. "Solution Mining of Uranium." Mining Congress Journal, Vol. 54 (January 1968). pp. 20-23.

[5] White, L. "In-Situ Leaching Opens New Uranium Reserves in Texas." Engineering and Mining Journal, Vol. 176 (July 1975). pp. 73-80.

[6] Hunkin, G.G. "The Environmental Impact of Solution Mining for Uranium." Mining Congress Journal, Vol. 61 (October 1975). pp. 24-27.

[7] Wyoming Mineral Corporation, *op.cit.*

At a pH above 4 the uranium precipitates out of solution.[1] This results in the collection of chemicals into fronts as the injected acid is consumed and the solution becomes less acidic.

The bicarbonate leaching solution generally has lower recovery values (60 to 70%) than those obtainable with sulfuric acid.[2] The advantage it offers, though, is that the uranium remains in solution over a wide range of alkaline concentrations (pH range of ~6 to 10).[3] This includes the natural alkaline concentration of the aquifer containing the ore formation. The collection of chemicals into fronts may still occur, particularly at the higher alkaline concentrations. However, the influence of the chemical front formation on the solubility of the uranium in the leaching solution is less critical than with the acid process.[4] In general, the minerals contained in the ore formation with the uranium do not react with the bicarbonate ion.

The majority of uranium solution mining operations in this country employ an alkaline leaching solution.[5,6,7,8] The solution consists of groundwater with hydrogen peroxide or oxygen to oxidize the uranium, and an alkaline chemical to react with the uranium and place it in solution.

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[1] Wyoming Mineral Corporation, Exploration and Mining Division. Environmental Report, Irigary Project, Johnson County, Wyoming. Lakewood, Colo.: Wyoming Mineral Corporation, 1977, p. 104.

[2] *Ibid.*, p. 105.

[3] *Ibid.*

[4] *Ibid.*

[5] *Ibid.*, p. 107.

[6] Exxon Company, U.S.A. Application for Amendment to Source Material License, SUA-1139 for Solution Mining of Uranium, Supplemental Environmental Report. Houston, Tex.: Exxon Company, 1977, p. 10-2.

[7] White, L. "In-Situ Leaching Opens New Uranium Reserves in Texas." Engineering and Mining Journal, Vol. 176 (July 1975), pp. 73-80.

[8] Hunkin, G. G. "The Environmental Impact of Solution Mining for Uranium." Mining Congress Journal, Vol. 61 (October 1975), pp. 24-27.

## Uranium Recovery Process

The recovery of uranium from the leaching solution consists typically of three operations: 1) leaching solution/sorption, 2) elution/precipitation, and 3) product drying/packaging. The process proposed for Wyoming Mineral Corporation's uranium solution mine located in Johnson County, Wyoming is typical of this type of recovery. A typical in-situ solution mining process is shown in Figure 5-12.[1]

In the leaching solution/sorption circuit, uranium is removed from the recovered uranium-bearing leaching solution by an ion exchange process which uses a solid ion exchange resin. In an ion exchange column, the uranium ions are removed from the leach solution by the resin. This process involves the uranium ions "exchanging" places with chloride ions which are present on the resin. The barren leaching solution now containing chlorine in place of uranium leaves the ion exchange unit and has hydrogen peroxide and ammonium bicarbonate added before being reinjected into the ore formation to repeat the leach cycle.

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[1] Wyoming Mineral Corporation, Exploration and Mining Division. Environmental Report, Irigary Project, Johnson County, Wyoming. Lakewood, Colo.: Wyoming Mineral Corporation, 1977. p. 10.

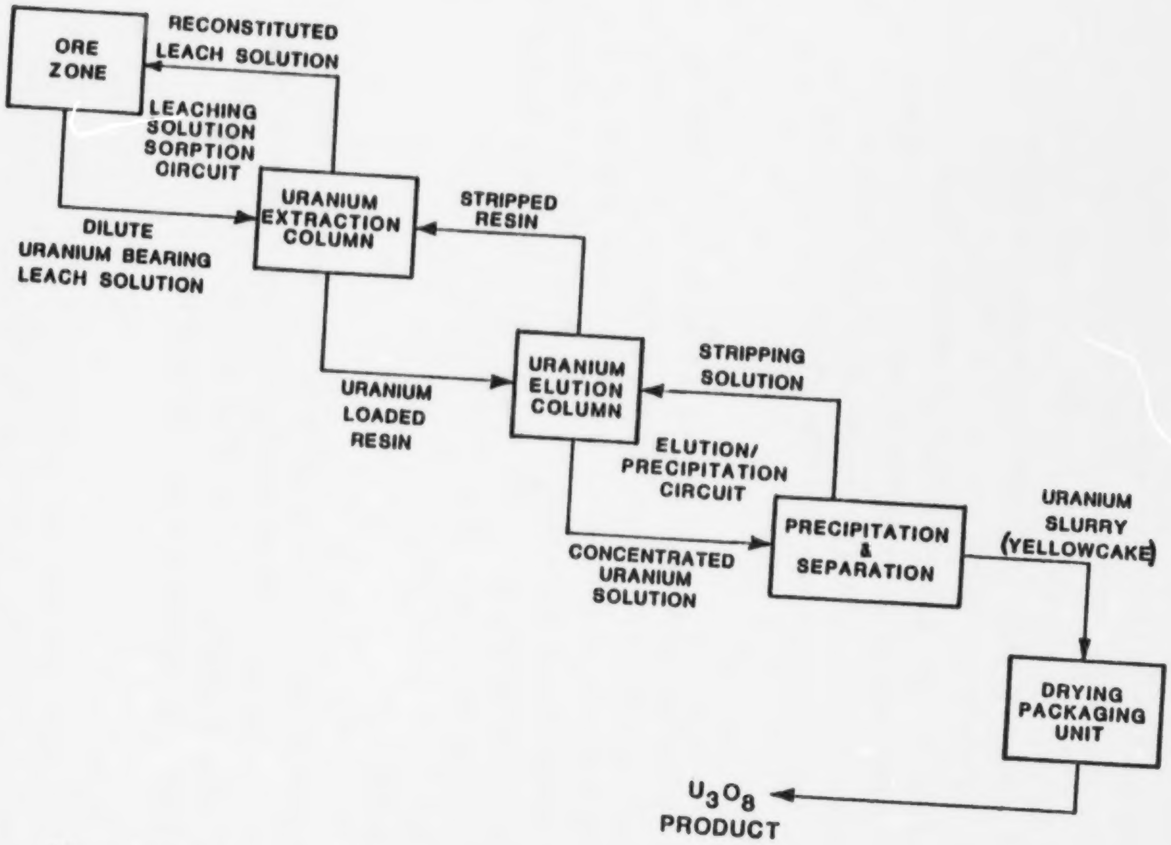
ORE ZONE
RECONSTITUTED LEACH SOLUTION
LEACHING SOLUTION SORPTION CIRCUIT
DILUTE URANIUM BEARING LEACH SOLUTION
URANIUM EXTRACTION COLUMN
STRIPPED RESIN
URANIUM LOADED RESIN
URANIUM ELUTION COLUMN
STRIPPING SOLUTION
ELUTION/ PRECIPITATION CIRCUIT
CONCENTRATED URANIUM SOLUTION
PRECIPITATION & SEPARATION
URANIUM SLURRY (YELLOWCAKE)
DRYING PACKAGING UNIT
$U_3O_8$ PRODUCT

Figure 5-12. In-Situ Solution Mining Uranium Recovery Process

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Source: Wyoming Mineral Corporation, Exploration and Mining Division. Environmental Report, Irigary Project, Johnson County, Wyoming. Lakewood, Colo.: Wyoming Mineral Corporation, 1977, p. 11.

The second operation in the uranium recovery process is the elution/precipitation operation. As the ion exchange resin becomes saturated with uranium, it is transferred from the ion exchange column to an elution column. In the elution column uranium is removed from the uranium saturated resin with an ammonium chloride solution ($\sim$1 to 2 $\underline{M}$ $NH_4Cl$).[1] In this operation uranium ions are essentially removed from the resin and replaced again with chloride ions. The uranium-barren resin is returned to the ion exchange column and the concentrated uranium solution goes to the precipitation and separation process.

In the precipitation step ammonia is added to the uranium solution which precipitates the uranium as ammonium diuranate.[2] The precipitated uranium is separated and sent to a dryer/packaging unit where it is processed to obtain the final $U_3O_8$ product. The uranium-barren solution is treated and returned to the elution column to repeat the process.

## Aquifer Restoration

After the ore formation is mined out, the aquifer containing the ore formation must be returned to some agreed upon water quality. The techniques available for the restoration of an aquifer fall into three general categories: "total water removal"; "water removal, clean-up and recycle"; and "in-situ restoration".[1]

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[1] Wyoming Mineral Corporation, Exploration and Mining Division. Environmental Report, Irigary Project, Johnson County, Wyoming. Lakewood Colo.: Wyoming Mineral Corporation, 1977. p. 32.

[2] *Ibid.*, p. 32.

In "total water removal", contaminated water is pumped from the aquifer and surrounding ground water flows into the leached ore formation to flush away contaminants. The removed water is not reinjected into the ore formation aquifer, but is either evaporated, used in irrigation, or sent to a deep disposal well.

In the second method "water removal, clean-up and recycle", contaminated water is pumped from the aquifer, treated aboveground and then reinjected into the aquifer where it originated. This process is similar to the original solution mining method in that it removes minerals (contaminants) from the aquifer and concentrates them aboveground. Examples of aboveground treatment techniques are given in Table 5-46.

The third method of aquifer restoration, the "in-situ" method, involves the treatment of the underground aquifer to produce the desired water quality without aboveground treatment. Chemicals are injected into the aquifer which would reprecipitate any chemical species that were mobilized by the leaching solution. This technique may be practical for those species that can be stabilized underground by precipitation or other techniques. However, it can only partly

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[1] Wyoming Mineral Corporation, Exploration and Mining Division. Environmental Report, Irigary Project, Johnson County, Wyoming. Lakewood, Colo: Wyoming Mineral Corporation, 1977. p. 158.

## TABLE 5-46. METHODS FOR GROUNDWATER TREATMENT

| Above Ground Treatment Processes |
|---|
| a. Reverse Osmosis |
| b. Electrodialysis |
| c. Ion Exchange |
| d. Conventional Evaporation with Water Recycle |
| e. Ultrafiltration |
| f. Chemical Precipitation |
| g. Ammonia Air Stripping |

Source: Wyoming Mineral Corporation, Exploration and Mining Division. Environmental Report, Irigary Project, Johnson County, Wyoming. Lakewood, Colo.: Wyoming Mineral Corporation, 1977, p. 160.

restore the aquifer since the method cannot effectively remove dissolved species such as ammonia and chloride.[1]

The aquifer restoration techniques currently in use or proposed by commercial in-situ mining processes include the "total water removal" method employing deep wells and evaporation ponds, and the "water removal, clean-up and recycle method".[2,3,4] The recycle method will be discussed here because it is commonly used and because it minimizes residuals by not requiring a disposal well or an evaporation pond for solar evaporation.

When cells of a well field are removed from production, the leaching solution still remaining in the area depleted is pumped out and injected into the new area to be mined. At the same time, uncontaminated aquifer water from the new area is pumped into the depleted area. A buffer zone where no mining is taking place is needed between the mining and restoration areas so no hydraulic coupling of the two operations can occur. This is shown in Figure 5-13.[5] After the majority of the leaching solution has

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[1] Wyoming Mineral Corporation, Exploration and Mining Division. Environmental Report, Irigary Project, Johnson County, Wyoming. Lakewood, Colo.: Wyoming Mineral Corporation, 1977. p. 165.

[2] *Ibid.*, p. 170.

[3] Exxon Company, U.S.A. Application for amendment to source material license SUA-1139 for solution mining of uranium, Supplemental Environmental Report. Houston, TX.: Exxon Company, 1977. pp. 3-31.

[4] White, L. "In-situ leaching opens new uranium reserves in Texas". Engineering and Mining Journal, Vol. 176 (July 1975), pp. 73-80.

[5] Wyoming Mineral Corporation, *op.cit.*, p. 172.

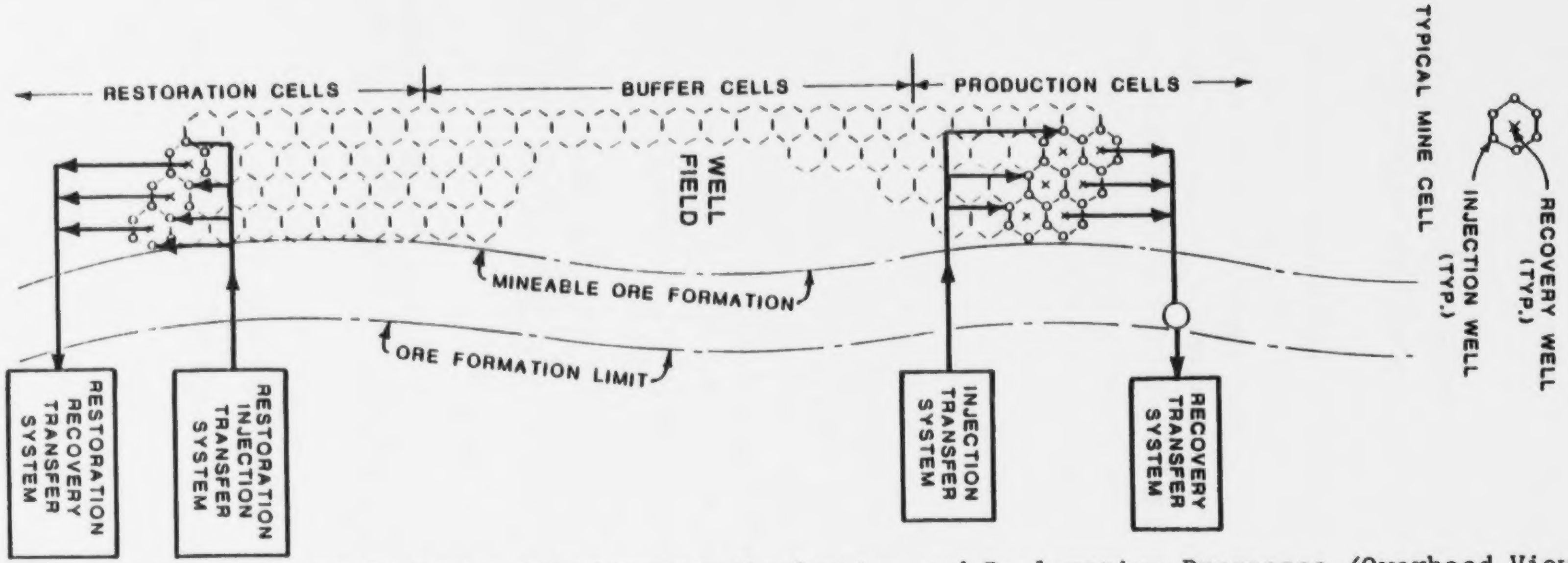
RESTORATION CELLS
BUFFER CELLS
PRODUCTION CELLS
TYPICAL MINE CELL
RECOVERY WELL (TYP.)
INJECTION WELL (TYP.)
WELL FIELD
MINEABLE ORE FORMATION
ORE FORMATION LIMIT
RESTORATION RECOVERY TRANSFER SYSTEM
RESTORATION INJECTION TRANSFER SYSTEM
INJECTION TRANSFER SYSTEM
RECOVERY TRANSFER SYSTEM

Figure 5-13. Well Field During Simultaneous Production and Reclamation Processes (Overhead View).

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Source: Wyoming Mineral Corporation, Exploration and Mining Division. Environmental Report, Irigary Project, Johnson County, Wyoming. Lakewood, Colo.: Wyoming Mineral Corporation, 1977, p. 172.

been pumped from the restoration area, the process of "water removal, clean-up and recycle" begins and continues until the restoration area has been returned to some agreed upon water quality. The quality of water to be left in the aquifer after restoration is decided between the mining company and the state water quality board before mining begins.

One proposed water clean-up process is shown in Figure 5-14.[1] This process removes hardness chemicals such as calcium and magnesium by cold-lime softening in the first stage of processing. After the hardness removal, the overflow solution is further treated to remove the remaining impuruties. The impurities of primary concern are ammonia and total dissolved solids (TDS).

The removal of these impurities is accomplished by first feeding the overflow solution to a reverse osmosis (RO) unit. The unit would produce a TDS content comparable to baseline water quality. The cleaned solution (permeate solution) from the RO unit is then fed to a final chemical treatment unit and transferred to the well field for reinjection into the aquifer.

### 5.4.3.2 Input Requirements

#### 5.4.3.2a Manpower Requirements

An in-situ mining project begins with a program of testing as described in the technology section. This test program would last typically 18 months. The U.S. Bureau of Mines has given the manpower requirements shown in Table 5-47 as typical permanent

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[1] Wyoming Mineral Corporation, Exploration and Mining Division. Environmental Report, Irigary Project, Johnson County, Wyoming. Lakewood, Colo.: Wyoming Mineral Corporation. 1977. p. 172.

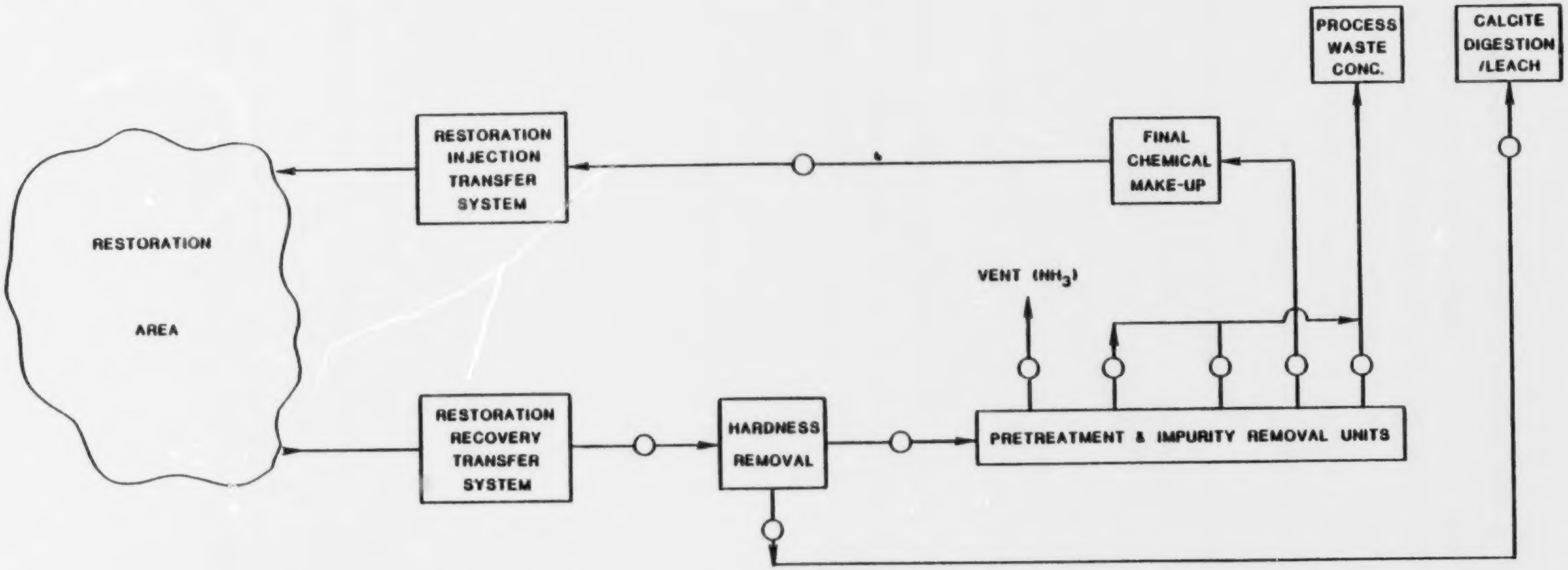
RESTORATION
AREA
RESTORATION INJECTION TRANSFER SYSTEM
RESTORATION RECOVERY TRANSFER SYSTEM
HARDNESS REMOVAL
PRETREATMENT & IMPURITY REMOVAL UNITS
VENT ($NH_3$)
FINAL CHEMICAL MAKE-UP
PROCESS WASTE CONC.
CALCITE DIGESTION /LEACH

Figure 5-14. Aquifer Water Clean-Up Process

Source: Wyoming Mineral Corporation Exploration and Mining Division. Environmental Report. Irigary Project, Johnson County, Wyoming. Lakewood, Colo.: Wyoming Mineral Corporation, 1977, p. 172.

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manpower usage for a pilot test program.[1] In addition to the personnel shown in the table, a geologist, hydrologist, reservoir engineer, petroleum engineer, metallurgists, and mechanical engineers would be used periodically.[2,3]

TABLE 5-47. SCHEDULE OF MANPOWER REQUIREMENTS FOR AN IN-SITU SOLUTION MINE PILOT PLANT STUDY

| | Approximate Time Employed |
|---|---|
| Project Supervisor | 18 months |
| Chemical Engineer | 18 months |
| Chemical Technician | 16 months |
| General Laborers (3) | 5 months |
| Drill Rig Operators (2) | ∿1 week |
| Water Truck Operator | ∿1 week |

Source: Larson, W.C., Geologist. Twin Cities Mining Research Center, U.S. Bureau of Mines. Information from telephone conversation. November 23, 1977.

The geologist and hydrologist would be employed to make the regional and local hydrology surveys, geophysical survey, and water sampling program prior to construction of the pilot plant. The number of wells required to construct a pilot plant could be drilled in about a week. As the wells are drilled, tests would be made and the results analyzed by a reservoir engineer, petroleum engineer, and a metallurgist to determine the characteristics

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Larson, W.C., Geologist, Twin Cities Mining Research Center, U.S. Bureau of Mines. Information from telephone conversation. November 23, 1977.

Hunkin, G.G., "The Environmental Impact of Solution Mining for Uranium". Mining Congress Journal, Vol. 61 (October 1975). pp. 24-27.

Frank, J.N. "Cost Model for Solution Mining of Uranium." Presented at the Uranium Industry Seminar. Grand Junction, CO. October 19-20, 1976.

of the ore formation. The chemical engineer supervises construction and operation of the plant. The chemical technician performs chemical analyses of samples taken during the test program. Operation of the pilot plant requires about three laborers for five months.

The construction of a 500,000 lb/yr processing plant for an in-situ solution mine would take approximately 12-18 months.[1,2] During this period chemical, civil, electrical, and mechanical engineers would be involved in insuring the plant is being constructed according to design and to aid in the startup of the plant. The type of craftsman that could be needed to construct the plant might be pipefitters, electricians, boilermakers, ironworkers, and carpenters. General laborers would be required to assist in the different phases of constructing the plant. One company has estimated that it will employ 20-43 people during the construction phase of a 500,000 lb/yr in-situ mining process.[3]

A typical commerical operation of a 500,000 lb/yr in-situ solution mining operation would employ 45-55 people. Of these people, a typical breakdown would be 25 professional and 30 general labor. An additional 12 people would make up a supporting staff off site at a home office.[4]

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[1] Frank, J. N. "Cost Model for Solution Mining of Uranium", Presented at the Uranium Industry Seminar. Grand Junction, Colo., October 19-20, 1976. 25 pp.

[2] Phillips, P. E. "A Comparison of Open Pit and In-Situ Leach Economics", Presented at the Conference on Uranium Mining Technology. Reno, Nevada, April 28, 1977.

[3] Ryan, F. M. "Energy Activity Profile", Lakewood, Colo,: Wyoming Mineral Corporation, November 1977.

[4] Larson, W. C., Geologist. Twin Cities Mining Research Center, U.S. Bureau of Mines. Information from telephone conversation. November 23, 1977.

In order to replace wells in mined-out areas with wells in unmined areas, a continuous drilling operation is needed. This work is generally let out to a local drilling contractor. It would involve using 2-3 drill rigs about 14 hours a day. It would require 2 laborers per rig per shift and 2 water truck operators per shift to support this effort.[1]

### 5.4.3.2b Materials and Equipment

The material and equipment requirements for an in-situ solution mine can be divided into two separate requirements, those for the well field and those for the uranium extraction process. The well field will consist of injection, production, and monitor (or observation) wells. These wells will be drilled using standard water well drill rigs. These rigs use a circulating mud solution to carry drill cuttings to the surface and therefore require a water truck as a source of water to make the drilling mud.

After the wells are drilled, they are completed with a string of PVC, fiberglass, and/or steel casing.[2] The casing is cemented in place by pumping cement down the casing and forcing it out into the annular space between the casing and drill hole. The amount of cement used will depend on what is required to isolate the ore zone from the aquifers above it. A typical well completion is shown in Figure 5-15.[3] This figure shows how a

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[1] Larson, W. C., Geologist. Twin Cities Mining Research Center, U.S. Bureau of Mines. Information from telephone conversation. November 23, 1977.

[2] Exxon Company, U.S.A. Application for amendment to source material license SUA-1139 for solution mining of uranium, Supplemental Environmental Report. Houston, TX.: Exxon Company, 1977. pp. 3-4.

[3] *Ibid.*, pp. 3-4.

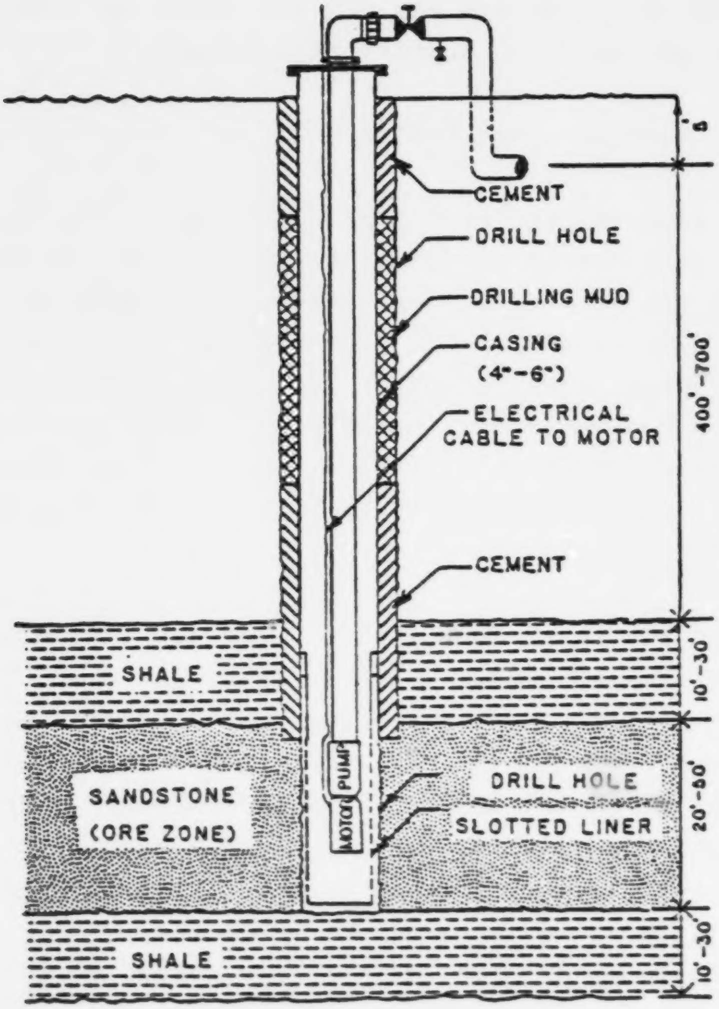
5'
CEMENT
DRILL HOLE
DRILLING MUD
CASING
(4"-6")
ELECTRICAL
CABLE TO MOTOR
400'-700'
CEMENT
SHALE
10'-30'
PUMP
MOTOR
SANDSTONE
(ORE ZONE)
DRILL HOLE
SLOTTED LINER
20'-80'
SHALE
10'-30'

Figure 5-15. Typical Production Well Completion

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Source: Exxon Company, U.S.A. Application for Amendment to Source Material license SUA-1139 for solution mining of uranium, Supplemental Environmental Report. Houston, Tx.: Exxon Company, 1977, p. 3-4.

screen or slotted lines are inserted into the ore zone area to selectively inject or recover leach solution. The requirement for a 500 ft. well cemented to the surface is 500 ft. of casing material and approximately 1310 lbs of cement.[1] A production well would have some sort of pumping unit associated with its assembly to pump the leaching solution to the surface.

The pipeline system connecting the well field to the uranium extraction plant would typically consist of 4 to 10 inch trunklines between the plant and the well field header sites and 1.5 to 2 inch flowline pipe from the header to the individual wells.[2] All lines would be buried below the frost line at an average depth of about 5 feet. The lines would be PVC, high density polyethylene, fiberglass, and/or coated and wrapped steel, depending on the size and operating conditions of the various segments of the system.[3] The length of pipe needed will depend on the distance of the well field from the plant. This distance will increase as the area around the plant is mined out and more distant wells are brought into service.

The uranium extraction plant as described in the previous section on in-situ solution mining technology is made up of various system components. These components and their function are outlined in Table 5-48. Sizes and quantities of these components are not available from the mining companies at this time. The process equipment will be housed in a heated building

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[1] Campbell, M. D. and J. H. Lehr. Water Well Technology. New York, N.Y.: McGraw-Hill Book Company, 1974. p. 622.

[2] Exxon Company, U.S.A. Application for amendment to source material license SUA-1139 for solution mining of uranium, Supplemental Environmental Report. Houston, TX.: Exxon Company, 1977. pp. 3-9.

[3] *Ibid.*

## TABLE 5-48. EQUIPMENT REQUIREMENTS FOR AN IN-SITU SOLUTION MINING PLANT

| Component | Function |
|---|---|
| Surge Tanks | Storage of pregnant and barren leach solutions |
| Ion Exchange Columns | Adsorption of uranium from leach solution onto resin beads |
| Resin Transfer Units | Transfer uranium loaded resin to elution columns |
| Elution Columns | Strip uranium complex from resin beads |
| Decarbonator | Vessel where the uranium carbonate complex is broken down using HCl |
| Precipitators | Vessels where $NH_3$ is added to precipitate the uranium as ammonium bicarbonate |
| Dewatering Units | Separates the solution from the precipitator into a uranium barren liquid fraction and a uranium rich slurry |
| Dry/Pack Unit | Removes water from uranium slurry and processes to a packaged yellowcake product |
| Makeup Tanks | Required for leach solution makeup and eluant solution makeup |
| Contaminant Control Units | Required to remove calcium carbonate from leach solution and to remove contaminants from eluant |
| Waste Storage Ponds | For storage of liquid and dissolved solids waste |

for protection from the weather. Another building at the plant would be an office/laboratory building. A typical plant layout is shown in Figure 5-16.[1]

Chemical material requirements for a 500,000 lb/yr plant are given in Table 5-49. There would also be an initial charge of resin beads for the ion exchange/elution circuit which would have to be added to as the initial charge becomes degenerated.

TABLE 5-49. CHEMICAL ADDITION REQUIREMENTS FOR A 500,000 LBS/YR SOLUTION PLANT

| Location | Reagent | Estimated Use (lbs/hr) |
|---|---|---|
| Injection Solution Make-up | $CO_2$ | 75 - 225 |
| | $NH_3$ | 40 - 120 |
| | $H_2O_2$ | 75 - 250 |
| Decarbonation/ Precipitation Circuit | HCl | 25 - 70 |
| | $NH_3$ | 5 - 20 |
| Eluant Make-up | $NH_4HCO_3$ | 35 - 100 |
| | $NH_4Cl$ | 75 - 200 |
| Dry/Pack Unit | Fuel (Propane) | 20 - 60 |
| Scrubber | Combustion Air | < 6700 |

Source: Wyoming Mineral Corporation, Exploration and Mining Division. Environmental Report, Irigary Project, Johnson County, Wyoming. Lakewood, Colo.: Wyoming Mineral Corporation, 1977. p. 31.

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[1] Exxon Company, U.S.A. Application for Amendment to Source Material License SUA-1139 for Solution Mining of Uranium, Supplemental Environmental Report. Houston, TX.: Exxon Company 1977. pp. 3-37.

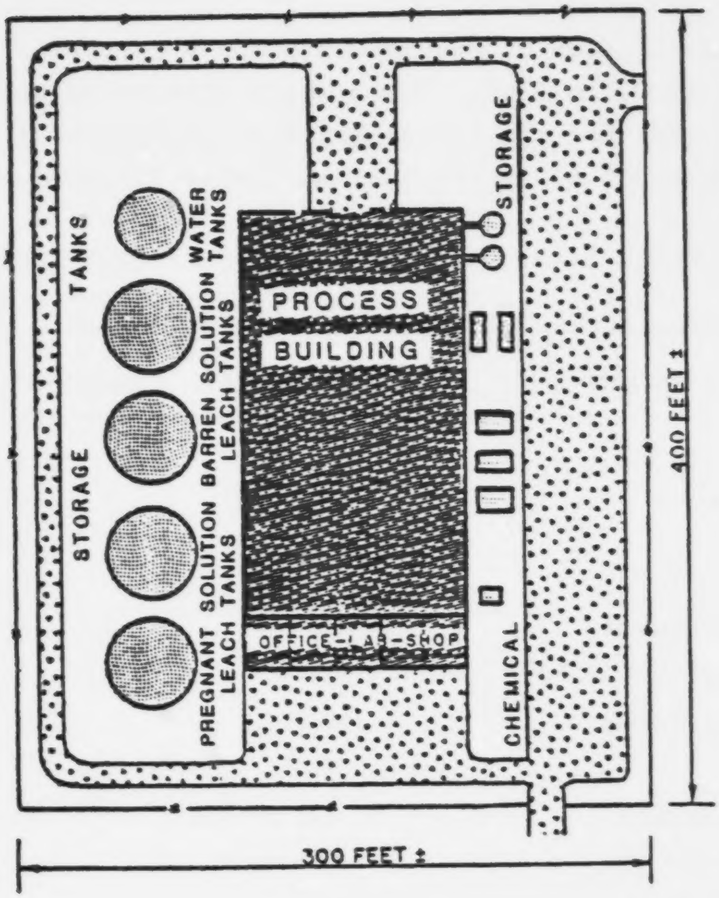
STORAGE
TANKS
WATER TANKS
BARREN SOLUTION LEACH TANKS
PREGNANT SOLUTION LEACH TANKS
PROCESS
BUILDING
OFFICE-LAB-SHOP
STORAGE
CHEMICAL
400 FEET ±
300 FEET ±

Figure 5-16. In-Situ Solution Mine Plan Layout

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Source: Exxon Company, U.S.A. Application for Amendment to Source Material License SUA-1139 for Solution Mining of Uranium, Supplemental Environmental Report. Houston, Tx.: Exxon Company, 1977, p. 3-37.

### 5.4.3.2c Economics

In a recent study by P. E. Phillips of the Rocky Mountain Energy Company, in-situ solution mining economics were compared to open pit economics.[1] The in-situ mining basis for the cost model are shown in Table 5-50. While this study considered an acid leach process, most costs for a basic leach process would be the same with the exception of mild steel replacing fiberglass reinforced plastic tanks for about a 20% savings in equipment costs.[2]

The operating costs and initial investment for the cost model and scaled costs for a 500,000 lb/yr plant are shown in Tables 5-51 and 5-52. All costs are in 1977 dollars. The case studied was for a 250,000 lb/yr mine. Scaling these costs to meet a 500,000 lb/yr production rate would be allowable since most mines are made up of 250,000 lb/yr modules. Some processes have the modules sharing a common decarbonization/precipitation circuit and drying/packaging unit. These components represent a small portion of the capital and operating expenses and therefore introduce little error in the scaleup of these expenses for a 500,000 lb/yr plant.

Tables 5-53 and 5-54 give the operating and capital costs for in-situ mines operating with two different grades of ore. The costs shown have been scaled from a 250,000 lb/yr to a 500,000 lb/yr mine. The case study showed that an in-situ mining operation had a higher rate of return and a shorter payment period when compared to an open pit mine.[3] The shorter payout period

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[1] Phillips, P.E. "A Comparison of Open Pit and In-Situ Leach Economics." Presented at the Conference on Uranium Mining Technology. Reno, Nevada. April 28, 1977.

[2] *Ibid.*

[3] *Ibid.*

TABLE 5-50. BASIS FOR COST STUDY FOR AN IN-SITU LEACH PLANT

250,000 lbs $U_3O_8$/Year Plant in Wyoming

WELL FIELD - 500 foot total depth
- Line drive patterns with well reversal
- Equal no. of production and injection wells
- 10% monitor wells
- 5" PVC casing, cemented to surface
- 5% well failures
- 60% underground recovery
- 50 ppm $U_3O_8$ solution strength
- 10 gpm/well injection rate
- 50 ft. well spacing

PLANT - Sulfuric acid leach
- I-X followed by S-X (Eluex)*
- 316 SS pumps
- PVC piping
- FRP tanks

18 month construction period

12 year mine life

*Calcined yellowcake as final product

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Source: Phillips, P. E. "A Comparison of Open Pit and In-Situ Leach Economics", Presented at the Conference on Uranium Mining Technology. Reno, Nevada, April 28, 1977.

TABLE 5-51. IN-SITU COST MODEL AND SCALED OPERATING COSTS FOR A 500,000 LB/YR MINE, 0.05 % $U_3O_8$ (1977 dollars)

| Item | Operating Costs ($/lb) | |
|---|---|---|
| | 250,000 lb/yr plant | 500,000 lb/yr plant |
| Well Field | 15.28 | 15.28 |
| Milling | 6.76 | 6.76 |
| G & A[a] | 1.40 | 0.70 |
| Reclamation | 0.34 | 0.34 |
| Royalty and Taxes | 2.00 | 2.00 |
| TOTAL | 25.78 | 25.08 |

[a] This total cost is assumed to be the same for a 250,000 and 500,000 lb/yr mine.

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Source: Phillips, P. E. "A Comparison of Open Pit and In-Situ Leach Economics," Presented at the Conference on Uranium Mining Technology. Reno, Nevada, April 28, 1977.

TABLE 5-52. IN-SITU LEACH COST MODEL AND SCALED INVESTMENT COSTS FOR A 500,000 LB/YR MINE (1977 dollars)

| Item | Investment Costs ($10^6$ $) | |
|---|---|---|
| | 250,000 lb/yr plant | 500,000 lb/yr plant |
| Mobile Equipment | 2.3 | 4.6 |
| Mill and Tailings[a] | 6.5 | 8.3 |
| Roads, Site Preparation | 1.0 | 2.0 |
| TOTAL CAPITAL | 9.8 | 14.9 |
| Working Capital | 1.4 | 2.8 |
| Initial Well Field | 2.2 | 4.4 |
| Infrastructure[b] | 1.3 | 1.3 |
| TOTAL INVESTMENT | 14.7 | 23.4 |

[a] This cost was reduced by 20% and a factor of 1.6 applied as derived from: Peters and Timmerhaus. Plant Design and Economics for Chemical Engineers. New York, N.Y.: McGraw-Hill, 1968, p. 124.

[b] This total cost is assumed to be the same for a 250,000 and 500,000 lb/yr mine.

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Source: Phillips, P. E. "A Comparison of Open Pit and In-Situ Leach Economics," Presented at the Conference on Uranium Mining Technology. Reno, Nevada, April 28, 1977.

TABLE 5-53. IN-SITU MINING OPERATING COSTS FOR TWO GRADES OF URANIUM ORE - 500,000 LB/YR MINE (1977 dollars)

| Item | Operating Costs ($/lb) | |
|---|---|---|
| | 0.1% $U_3O_8$ | 0.05% $U_3O_8$ |
| Mining | 5.90 | 15.28 |
| Milling | 6.76 | 6.76 |
| G & A | 0.70 | 0.70 |
| Reclamation | 0.12 | 0.34 |
| Royalty & Taxes | 2.00 | 2.00 |
| TOTAL | 15.48 | 25.08 |

Source: Phillips, P. E. "A Comparison of Open Pit and In-Situ Leach Economics," Presented at the Conference on Uranium Mining Technology. Reno, Nevada, April 28, 1977.

TABLE 5-54. IN-SITU MINING INVESTMENT COSTS FOR TWO GRADES OF URANIUM ORE - 500,000 LB/YR MINE (1977 dollars)

| Item | Investment Costs ($10^6$ $) | |
|---|---|---|
| | 0.1% $U_3O_8$ | 0.05% $U_3O_8$ |
| Mine Mobile & Shops | 2.4 | 4.6 |
| Mill & Tailings | 8.3 | 8.3 |
| Roads, Site Preparation | 2.0 | 2.0 |
| TOTAL CAPITAL | 12.7 | 14.9 |
| Working Capital | 1.8 | 2.8 |
| Initial Well Field | 6.0 | 4.4 |
| Infrastructure | 1.3 | 1.3 |
| TOTAL INITIAL INVESTMENT | 21.8 | 23.4 |

Source: Phillips, P. E. "A Comparison of Open Pit and In-Situ Leach Economics," Presented at the Conference on Uranium Mining Technology. Reno, Nevada, April 28, 1977.

indicates that in-situ solution mining could be applied to small deposits with fewer operating years than that required for conventional mining. The rate of return for an in-situ solution mine producing $U_3O_8$ at a rate of 250,000 lb/yr would range between about 20 to 40%.[1]

A sensitivity analysis involving some major parameters of in-situ mining economics is shown in Table 5-55. The effect of increasing the recovery of uranium, pregnant leaching solution strength, injectivity of the formation, and well spacing by 10% and decreasing well costs by 10% is investigated. The effect is shown on economic considerations such as the number of wells per year which would have to be drilled, the cost of drilling the wells, the cost of producing the product, the rate of return, and present value. The number of wells and well field costs are considered since they make up a large portion of the operating costs for an in-situ mine. Most of the well field costs are a direct function of the number of wells required to provide a desired production rate. A completed well of 500 foot depth costs about $12 per foot if drilled and cemented with company-owned equipment for a total of $6,000 per well.[2]

The analysis of Table 5-55 leads to some interesting conclusions. Recovery of uranium from the ore formation does not appear to be quite as important as well spacing and solution strength. The same relative increase in the pregnant leaching solution strength is more significant to the economics than well spacing because it not only reduces the well requirements, but also increases the capacity of the plant with little change in the capital required. Another fact is the increase in

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[1] Phillips, P.E. "A Comparison of Open Pit and In-Situ Leach Economics." Presented at the Conference on Uranium Mining Technology. Reno, Nevada. April 28, 1977.

[2] *Ibid.*

TABLE 5-55. IN-SITU MINE ECONOMICS SENSITIVITY ANALYSIS (250,000 LB/YR MINE)

| | Wells Per Year | Well Costs %/Lb | Change in Operating Cost $/Lb | Rate of Return % | Change in Present Value @ 10% $ Million |
|---|---|---|---|---|---|
| Base | 485 | 15.62 | -- | 20 | -- |
| +10% Recovery | 444 | 14.38 | 1.24 | 22 | 1.5 |
| +10% Solution Strength | 441 | 12.98 | 2.64 | 28 | 6.2 |
| +10% Injectivity | 441 | 14.28 | 1.34 | 23 | 1.8 |
| +10% Well Spacing | 402 | 12.90 | 2.72 | 25 | 3.5 |
| -10% Well Costs | 485 | 14.06 | 1.56 | 23 | 2.0 |

Source: Phillips, P. E., "A Comparison of Open Pit and In-Situ Leach Economics", Presented at the Conference on Uranium Mining Technology, Reno, Nevada, April 28, 1977.

net present value associated with the increase in solution strength. This $6.2 million increase amounts to more than $2,000 per well (after tax) over the life of the project.[1] This indicates that more costly well completions would be justified if they resulted in better solution strength. Also the effect of reducing the well costs directly is not as significant as solution strength or well spacing, but is more significant than an increase in recovery.

### 5.4.3.2d Water Requirements

The major water requirements for an in-situ uranium mining operation are for the well drilling and leaching solution processing associated with the mining operation. These requirements are listed in Table 5-56. To maintain a production rate of 500,000 lb/yr of yellowcake about 30 acres of well field per year would be drilled.[2] A 7-spot well pattern used in the well field would require about 28 production and injection wells[3] and about 7 observation wells.[4] On this basis approximately 3 wells must be completed per day to maintain a 500,000 lb/yr production rate. This is not unreasonable as a 500 foot well can be completed by one drilling crew in a day.[5] The water requirement for drilling is for making the drilling mud solution. The amount of solution required for a 500 foot well is about 3140 gallons of water.[1] The water requirements for three wells a day would be about 9420 gallons/day.

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[1] Phillips, P.E. "A Comparison of Open Pit and In-Situ Leach Economics." Presented at the Conference on Uranium Mining Technology. Reno, Nevada. April 28, 1977.

[2] Wyoming Mineral Corporation, Exploration and Mining Division. Environmental Report, Irigary Project, Johnson County, Wyoming. Lakewood, CO: Wyoming Mineral Corporation. 1977. p. 33.

[3] Larson, W.C., Geologist. Twin Cities Mining Research Center, U.S. Bureau of Mines. Information from Telephone Conversation. December 8, 1977.

[4] Exxon Company, U.S.A. Application for Amendment to Source Material License SUA-1139 for Solution Mining of Uranium, Supplemental Environmental Report. Houston, TX: Exxon Company. 1977.

[5] Larson, W.C., *op.cit.*

TABLE 5-56. WATER REQUIREMENTS FOR A 500,000 LB/YR IN-SITU SOLUTION MINE

| Item | Water Requirement (gallons/day) |
|---|---|
| Drilling Operations[a] | 9,425 |
| Process Water | 51,000 |
| Aquifer Restoration | 121,000 |
| Sanitary Water | 2,000 |

[a] Calculated

Source: Wyoming Mineral Corporation, Exploration and Mining Division. Environmental Report, Irigary Project, Johnson County, Wyoming. Lakewood, CO: Wyoming Mineral Corporation. 1977. pp. 34, 35, & 175.

The total process use of water for a 500,000 lb/yr uranium solution mining operation would be at the most 51.0 x $10^3$ gallons/day.[2] This includes the overproduction of the well field to insure the leaching solution doesn't escape the mining area, water for injection well cleaning, and resin wash water. In addition to this, water usage from the aquifer restoration would amount to around 121 x $10^3$ gallon/day.[3] Also an estimated 2000 gallons/day would be required for sanitary water use.[4]

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[1] Larson, W.C., Geologist. Twin Cities Mining Research Center, U.S. Bureau of Mines. Information from Telephone Conversation. December 8, 1977.

[2] Wyoming Mineral Corporation, Exploration and Mining Division. Environmental Report, Irigary Project, Johnson County, Wyoming. Lakewood, CO: Wyoming Mineral Corporation. 1977. p. 35.

[3] *Ibid.*, p. 175.

[4] *Ibid.*, p. 34.

### 5.4.3.2e Land Requirements

Uranium deposits are generally located in ore formations which occur as small, separate fronts (20-50 acres) or as large, elongated fronts (1000 acres).[1,2] A 500,000 lb $U_3O_8$/yr production rate would mine about 25-50 acres/yr.[3] The mill process area would require about a 5-acre site.[4] The entire area of an in-situ mine and mill is removed from other usage.

An in-situ mining operation which will mine one uranium deposit with a 20-acre well field, another deposit with a 50-acre well field, and use a common milling process plant has stated that it will require 200 acres for the lifetime of the operation (∿10 years).[5] Another mining operation is going to mine an elongated front formation. It states that it will require 100 acres/yr for a 10-year lifetime.[6] Each of these operations would produce about 500,000 lb/yr of yellow cake. At the end of an in-situ mining operation, all of the land is restored for use as before the mining operation. A typical mining schedule is shown in Figure 5-17 for the mining of uranium from an ancient stream bed. The mining activities initiate in the proximity of the plant and progress stepwise along the stream bed.

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[1] Wyoming Mineral Corporation, Exploration and Mining Division. Environmental Report, Irigary Project, Johnson County, Wyoming. Lakewood, CO: Wyoming Mineral Corporation. 1977. p. 3.

[2] Exxon Company, U.S.A. Application for Amendment to Source Material License SUA-1139 For Solution Mining of Uranium, Supplemental Environmental Report. Houston, TX: Exxon Company. 1977. p. 3-5, 3-6.

[3] Wyoming Mineral Corporation, *op.cit.*, p. 5.

[4] *Ibid.*

[5] Exxon Company, U.S.A., *op.cit.*, p. 7-1

[6] Wyoming Mineral Corporation, *op.cit.*, p. 120.

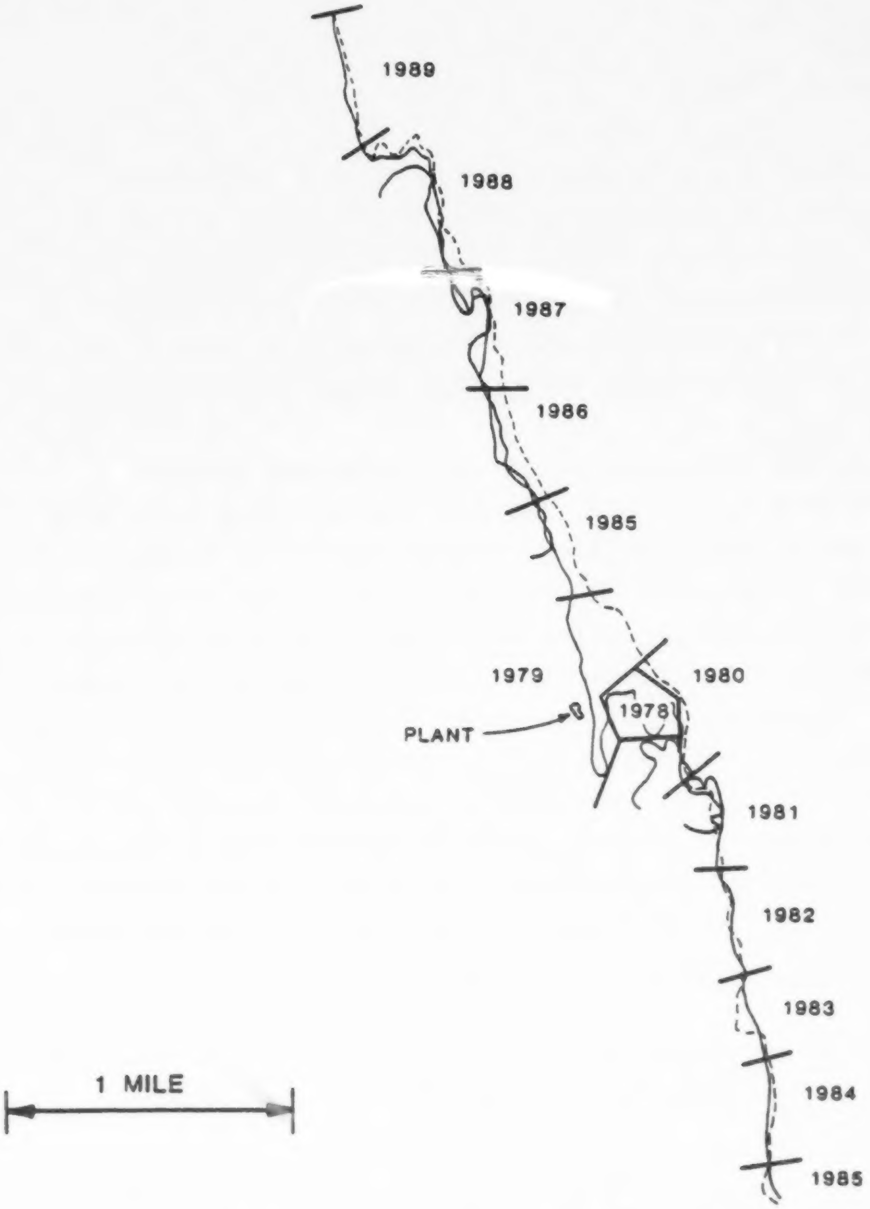
1989
1988
1987
1986
1985
1979
1980
1978
PLANT
1981
1982
1983
1984
1985
1 MILE

Figure 5-17. In-Situ Mine Land Use Schedule

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Source: Wyoming Mineral Corporation, Exploration and Mining Division. Environmental Report, Irigary Project, Johnson County, Wyoming. Lakewood, Colo.: Wyoming Mineral Corporation, 1977, p. 41.

### 5.4.3.2f Ancillary Energy

The major energy requirements for an in-situ mining process are for the pumping of fluids and the drying of the final product. Smaller amounts of energy are consumed in the process of drilling the injection, production, and monitoring wells. The power requirement for a 250,000 lb/yr uranium solution mining operation in George West, Texas is about 1500 kw.[1] This would be made up mainly of pumping energy needed to move solutions from the well field to the processing plant and operation of process equipment. Since solution mines are generally modularized into 250,000 lb/yr units, a good estimate for a 500,000 lb/yr plant electrical energy requirements would be 3000 kw.

The second major energy requirement in the uranium recovery process is that for drying the yellowcake product. Estimates for one 500,000 lb/yr mine in Wyoming are for the use of 20-60 lbs/hr of propane.[2] Using a heating value of 21,560 Btu/lb,[3] the energy requirements for the drying operation would range from 10 to 30 million Btu/day.

When the aquifer restoration program begins, additional power will be required to pump aquifer water solutions to the surface for treatment and then injection back into the aquifer (assuming "water removal, cleanup and recycle" method of restoration is used). One estimate for a rate of aquifer restoration to clean up 180 acre feet/year of contaminated water would provide that volume to be recycled 5 times for adequate contaminant removal.[1] This results in an energy requirement of about 85 kw (assuming total dynamic head of 500 ft and pump efficiency of 75%) or about 290 x $10^3$ Btu/hr.[2]

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[1] White, L. "In-Situ Leaching Opens New Uranium Reserves in Texas." Engineering and Mining Journal, Vol. 176 (July 1975), pp. 73-80.

[2] Wyoming Mineral Corporation, Exploration and Mining Division. Environmental Report, Irigary Project, Johnson County, Wyoming. Lakewood, Colo.: Wyoming Mineral Corporation, 1977, p. 31.

[3] Bland, W. F. and R. L. Davidson. Petroleum Processing Handbook. New York: McGraw-Hill Book Co., 1967, p. 11-10.

If it is assumed that a 3 well/day drilling rate is required to maintain a 500,000 lb/yr production rate (see Section 5.4.1.3.1.4), also allowing that one 185 HP drilling rig can drill a 500 ft well (assumed average depth for an in-situ solution mining well) in a 14 hour day,[3] then the estimated total energy requirement for operating 3 drilling rigs would be 122 x $10^6$ Btu/day. This estimate was made assuming a diesel fuel consumption of 0.066 gal/HP-hr and a heating value of 0.139 x $10^6$ Btu/gal for the fuel.

### 5.4.3.3 Outputs

Mining companies are reluctant to release data on residuals for their mining process because in-situ uranium mining is still in the research and development stage. Also, commercial scale in-situ operations have not been in operation long enough to generate sufficient data on effluents. Information presented in this section on air, liquid, and solid wastes will be, for the most part, a qualitative discussion of what is thought to make up a waste stream. Figure 5-18 will be used to discuss the effluents of a typical uranium recovery process producing 500,000 lb/yr of yellowcake.[1]

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[1] Wyoming Mineral Corporation, Exploration and Mining Division. Environmental Report, Irigary Project, Johnson County, Wyoming. Lakewood, Colo.: Wyoming Mineral Corporation. 1977. p. 175.

[2] Campbell, M.D. and J.H. Lehr. Water Well Technology. New York: McGraw-Hill Book Co. 1974. p. 601.

[3] Larson, W.C., Geologist, Twin Cities Mining Research Center, U.S. Bureau of Mines. Information from the telephone conversation. December 8, 1977.

#### 5.4.3.3a Air Emissions

The gaseous effluents for alkaline leach in-situ uranium mining are given in Table 5-57.[2] Effluents from the process plant and evaporation ponds are mainly $NH_3$, $CO_2$, and $NH_4Cl$. The $U_3O_8$ emissions are from losses through the scrubbing unit of the drying and packaging operation.

Air emissions from the mining reclamation process are not included with the information in Table 5-57. The source of these emissions would be an additional waste pond. This pond would have a surface area of about 30,000 $ft^2$.[3] It would be made up of a saline brine of pH$\sim$6 having a total dissolved solids content of $\sim$15,000 ppm, and containing $NH_4^+$, $NA^+$, $Ca^{+2}$, $Mg^{+2}$, $Cl^-$, and $SO_4^{-2}$ ions.[4] Radioactive elements would be present as uranium (10-500 ppm) and Ra-226 (100-1000 pCi/liter).[5] No information is available on what quantity of the elements present in the ponds will be emitted to the air through evaporation. It is likely that the emissions would be similar to those from the process evaporation ponds and include $NH_3$ and $NH_4Cl$ as the major gaseous effluents.

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[1] Wyoming Mineral Corporation, Exploration and Mining Division. Environmental Report, Irigary Project, Johnson County, Wyoming. Lakewood, Colo.: Wyoming Mineral Corporation, 1977, p. 30.

[2] *Ibid.*, p. 38.

[3] *Ibid.*, p. 117.

[4] *Ibid.*, p. 175.

[5] *Ibid.*

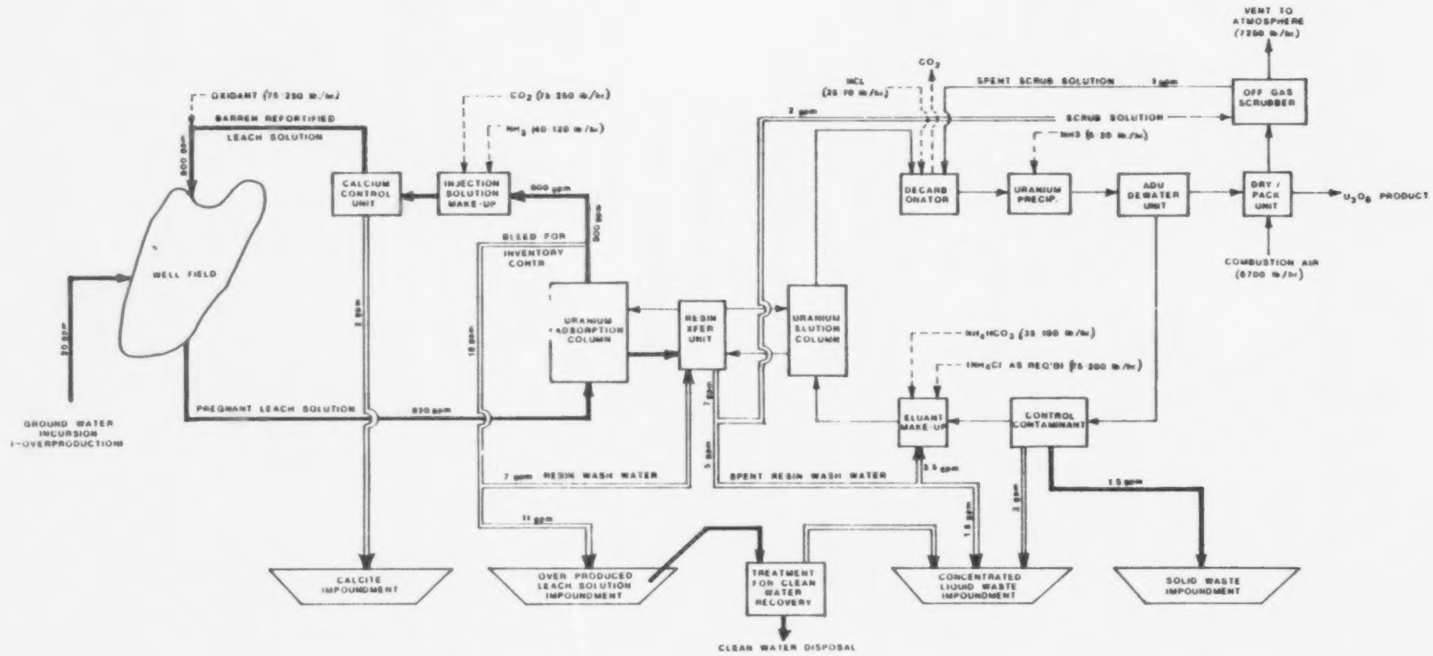
OXIDANT (75-250 lb/hr)
BARREN REFORTIFIED
LEACH SOLUTION
900 gpm
CO$_2$ (75-250 lb/hr)
NH$_3$ (40-120 lb/hr)
CALCIUM CONTROL UNIT
INJECTION SOLUTION MAKE-UP
900 gpm
900 gpm
BLEED FOR
INVENTORY
CONTR
WELL FIELD
20 gpm
GROUND WATER
INCURSION
(-OVERPRODUCTION)
2 gpm
18 gpm
URANIUM ADSORPTION COLUMN
RESIN XFER UNIT
PREGNANT LEACH SOLUTION
920 gpm
7 gpm RESIN WASH WATER
11 gpm
7 gpm
5 gpm
SPENT RESIN WASH WATER
URANIUM ELUTION COLUMN
HCL
(25-70 lb/hr)
CO$_2$
2 gpm
SPENT SCRUB SOLUTION
1 gpm
SCRUB SOLUTION
VENT TO
ATMOSPHERE
(7250 lb/hr)
OFF GAS SCRUBBER
NH3 (5-20 lb/hr)
DECARBONATOR
URANIUM PRECIP.
ADU DEWATER UNIT
DRY / PACK UNIT
U$_3$O$_8$ PRODUCT
COMBUSTION AIR
(6700 lb/hr)
NH$_4$HCO$_3$ (35-100 lb/hr)
(NH$_4$Cl AS REQ'D) (75-200 lb/hr)
ELUANT MAKE-UP
CONTROL CONTAMINANT
3.5 gpm
1.5 gpm
2 gpm
1.5 gpm
CALCITE IMPOUNDMENT
OVER PRODUCED LEACH SOLUTION IMPOUNDMENT
TREATMENT FOR CLEAN WATER RECOVERY
CLEAN WATER DISPOSAL
CONCENTRATED LIQUID WASTE IMPOUNDMENT
SOLID WASTE IMPOUNDMENT

Figure 5-18. In-Situ Mine Uranium Extraction Process.

Source: Wyoming Mineral Corporation, Exploration and Mining Division. Environmental Report, Irigary Project, Johnson County, Wyoming. Lakewood, Colo.: Wyoming Mineral Corporation, 1977, p. 31.

## TABLE 5-57. ESTIMATED AIR EMISSIONS

| Source | Emission Rate (lbs/yr) | | | |
|---|---|---|---|---|
| | $NH_3$ | $CO_2$ | $NH_4Cl$ | $U_3O_8$ |
| Uranium Recovery Process | $4\text{-}6\times10^3$ | $1\text{-}2\times10^6$ | $20\text{-}35\times10^3$ | 7-900 |
| Calcium Control Unit | $1.5\text{-}2.5\times10^3$ | $4\text{-}6\times10^3$ | 40-60 | -- |
| Calcite Storage Pond | $2.5\text{-}3.5\times10^3$ | $9\text{-}10\times10^3$ | $9.5\text{-}10.5\times10^3$ | -- |
| Liquid Waste Storage Ponds[a] | $48\text{-}56\times10^3$ | $36\text{-}40\times10^3$ | $140\text{-}160\times10^3$ | -- |

[a] Estimated assuming combined surface area of all ponds to be 4 acres.

Source: Wyoming Mineral Corporation, Exploration and Mining Division. Environmental Report, Irigary Project, Johnson County, Wyoming. Lakewood, Colo.: Wyoming Mineral Corporation, 1977. p. 38.

### 5.4.3.3b Water Effluents

The estimated worst case volumes of process wastes and effluents are given in Table 5-58[1] for a 500,000 lb/yr solution mining production facility. The wastes from this facility would be sent to ponds. All of the evaporation or storage ponds mentioned in this section are lined with a plastic liner. Each pond has a leak detection system so that when a leak occurs the pond can be evacuated to an adjacent pond while liner repairs are effected. Large leaks are detected by a noticeable drop in pond level. Smaller leaks are detected by sampling perforated pipes lying beneath the pond liner.

The largest volume of contaminated water generated by the solution mining process is the residual leaching solution left in the mined formation after mining is terminated prior to aquifer restoration. Assuming the restoration process is one of water removal, clean-up, and recycle, the waste stream generated from aquifer restoration would be approximately 135 acre-ft/yr.[2] This stream would be sent to a storage pond and evaporated to a solid.

The primary source of effluent water (~20 gpm) from the in situ process is the over-production of the well field.[3] This is done to insure that the leaching solution is confined within the mine boundaries. As seen from Figure 5-18, the overproduction is removed from the process in two different streams. The first is a waste stream from the calcium control

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[1] Wyoming Mineral Corporation, Exploration and Mining Division. Environmental Report, Irigary Project, Johnson County, Wyoming. Lakewood, Colo.: Wyoming Mineral Corporation, 1977, p. 34.

[2] *Ibid.*, p. 175.

[3] *Ibid.*, p. 33.

### TABLE 5-58. ESTIMATED VOLUMES OF PROCESS WASTES AND EFFLUENTS FOR A 500,000 LB/YR IN-SITU URANIUM SOLUTION MINE

| Receptor | Source | Estimated Volume Acre-ft/yr | Estimated Volume Gals/min. |
|---|---|---|---|
| Restoration Waste Storage Pond | Aquifer Restoration Process | 135 | 84 |
| Calcite Storage Pond | Calcium Control Unit | 3.2 | 2 |
| Over-produced Leach Solution Storage Pond | Bleed for Inventory Control | 18 | 11 |
| Concentrated Liquid Waste Storage Pond | Spent Resin Wash Water | 24 | 1.5 |
| | Eluant Circuit Contaminant Cont. | 5 | 3 |
| | Injection Well Cleaning | 14-23 | 9-14 |
| Solid Waste Storage Pond | Eluant Circuit Contaminant Control | 24 | 1.5 |
| Sanitary Waste Field | Sanitary Water Use | 2 | 1.3 |
| Ground Surface | Monitor Well Sampling | 1 | 0.6 |

Source: Wyoming Mineral Corporation, Exploration and Mining Division. Environmental Report, Irigary Project, Johnson County, Wyoming. Lakewood, Colo.: Wyoming Mineral Corporation, 1977. p. 34.

unit of about 2 gpm. This stream would produce 800 tons/yr of $CaCO_3$ containing 1-2 percent $U_3O_8$ by weight and 500-1200 pCi Ra-226/gm.[1] This stream is stored in a calcite storage pond as shown in Figure 5-18. The liquid is allowed to evaporate and after mining has stopped, the pond is reclaimed. Solids from the pond are either buried or removed.

The second stream is a direct bleed from the leaching solution circuit for inventory control. This stream is split into two different streams; one is used for resin wash water (∿7 gpm) and the other is wasted to a storage pond (∿11 gpm). The stream sent to the pond consists of the leaching solution after most of the complexed uranium has been exchanged for chloride ions in the ion exchange column.

The resin wash water is used in the resin transfer unit to limit chemical contamination between the sorption and elution circuits. The spent resin wash water leaving the resin transfer unit is expected to contain $NH_4^+$, $Cl^-$, $CO_3^{-2}$, and $HCO_3^{-2}$ ions and radioactive elements Ra-226, Th-230 and uranium.[2] The spent resin wash water is then sent to the drier off gas scrubber as a scrub solution (∿2 gpm), to the eluant make-up system (∿3.5 gpm), and to a storage pond (∿1.5 gpm).

Another major source of process effluent water is the eluant circuit bleed (∿4.5 gpm).[3] This source originates in the contaminant control unit which operates in the eluant circuit. This unit produces a liquid waste stream (∿3.0 gpm) containing alkali chlorides, carbonates, and sulfate salts which is sent to the concentrated liquids storage pond. A dissolved solids waste stream (∿1.5 gpm) made up, for the most part, of barium sulfate (<800 tons/yr) and small amounts of vanadium[1] is sent to the solid waste storage pond.

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[1] Wyoming Mineral Corporation, Exploration and Mining Division. Environmental Report, Irigary Project, Johnson County, Wyoming. Lakewood, CO: Wyoming Mineral Corporation. 1977. p. 37.

[2] Exxon Company, U.S.A. Application for Amendment to Source Material License SUA-1139 for Solution Mining of Uranium, Supplemental Environmental Report. Houston, TX: Exxon Company. 1977. p. 3-24.

[3] Wyoming Mineral Corporation, Exploration and Mining Division, *op.cit.*, p. 35.

Another source for process effluents is the routine injection well cleaning necessary to maintain leaching solution flows. This would result in a waste stream of 9-14 gpm[2] containing the residuals from the formation and well (mainly $CaCO_3$) carried along by the formation water withdrawn in the cleaning process. This stream would be sent to an evaporation pond for disposal.

The remaining water effluents would be from sanitary water use (∿1.3 gpm) and monitor well sampling (∿0.6 gpm).[3] The effluents due to sanitary water use would be sent to a sanitary waste field. It is assumed that the monitor well sample water would be pumped out onto the ground as it would contain local aquifer water.

### 5.4.3.3c Solid Waste

The solid wastes generated from in-situ solution mining primarily result from the material left after the water has evaporated from the waste ponds. This material would either be covered as the ponds are backfilled or removed from the site if it exceeds the allowable level of radioactivity.

The three principal sources of solid wastes in the solution mining process are the calcite storage pond, the solids waste storage pond and the other liquid waste storage ponds mentioned above. Additional solid wastes result from liquid waste storage ponds produced during the aquifer restoration process. These wastes are similar to those generated in the uranium recovery process and would be similarly treated.

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[1] Wyoming Mineral Corporation, Exploration and Mining Division. Environmental Report, Irigary Project, Johnson County, Wyoming. Lakewood, CO: Wyoming Mineral Corporation. 1977. p. 39.

[2] *Ibid.*, p. 35.

[3] *Ibid.*, p. 34.

One of the largest contributions to the solid waste of a solution mining operation comes from the removal of $CaCO_3$ (calcite) from the leaching solution circuit. The precipitated calcite would contain as much as 1-2 wt.% $U_3O_8$ and 500-1200 pCi of Ra-226 per gram. This would produce <800 tons/yr of calcite to be impounded in the calcite storage pond on site.[1]

Another major source of solid waste is that of the elution circuit contamination control unit waste storage. The unit is operated to remove sulfate and vanadium in order to maintain uranium extraction and/or product quality. The sulfate would be controlled by precipitation of barium sulfate resulting in <800 tons/yr of that compound being sent to the solids waste storage pond.[2]

The third source of solid wastes would be that resulting from evaporative concentration of impounded waste solutions. These precipitation products are expected to be an assortment of alkali chloride, carbonate and sulfate salts.[3] The rate and quantity of solids produced in this manner has not been determined at this time.

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[1] Wyoming Mineral Corporation, Exploration and Mining Division. Environmental Report, Iragary Project, Johnson County, Wyoming. Lakewood, CO: Wyoming Mineral Corporation. 1977. p. 37.

[2] *Ibid.*, p. 39.

[3] *Ibid.*

A solid waste not sent to ponds is generated by the elution circuit contamination control circuit. Vanadium control would be exercised using sorption from the eluant onto activated carbon. This would produce an as yet undetermined amount of spent carbon which would be drummed and stored.

One area of solid waste that is not generated in large quantities, but presents a material handling problem is that of radioactive solid waste. This waste would result from material periodically cleaned out of various vessels, spent ion-exchange resin, and spent equipment/parts coated with scale or that have been exposed to radioactive fluids for extended periods of time.[1] This material would exhibit radioactive levels requiring controlled disposition according to NRC (Nuclear Regulatory Commission) regulations. The quantity of this type of material which would be generated by a solution mining process has not been determined at this time.

### 5.4.3.3d Noise Pollution

The major noise problems associated with in-situ uranium mining would be with the drilling operations involved in this activity. Equipment used and noise levels expected would be similar to those for uranium exploration discussed earlier. Process equipment will be contained in a closed building for protection from the weather, therefore noise would only be a problem to employee health if it reached too high a level. Generally, solution mining has been located far enough from populated areas so that noise problems have not occurred.

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[1] Exxon Company, U.S.A. Application for Amendment to Source Material License SUA-1139 For Solution Mining or Uranium, Supplemental Environmental Report. Houston, TX: Exxon Company. 1977 p. 3-32.

### 5.4.3.3e Occupational Health and Safety

At this time there are only three commercial in-situ mining projects operating in this country. One of these projects has been in operation for approximately three years while the other two are expected to reach design capacity this year. As a result of this rather limited operating experience with in-situ solution mining, meaningful data on occupational health and safety statistics are not available.

Occupational safety hazards at an in-situ solution mine facility will result from five major areas: electrical, mechanical, chemical, environmental, and radioactive hazards. The major electrical equipment contributing to a safety hazard will be pumps, transformers, electrically operated switches, gauges, valves, agitators, and recording devices.[1]

Major mechanical equipment presenting a safety hazard typically will be 1) small, continuous steel-belt dryer for drying uranium precipitate (fully covered), 2) front-end loader, 3) agitators in precipitation tanks, 4) truck-mounted, water-well drill rigs, 5) road scraper, and 6) trucks.[2]

There will be several chemical reagents stored on the in-situ solution mine site. These will include typically carbon dioxide (gas), hydrogen peroxide (50%) (liquid), anhydrous ammonia (liquid), hydrochloric acid (50%), ammonium chloride (solid), and ammonium bicarbonate (solid).[3] These chemicals are potentially dangerous to operating personnel if allowed to contact the skin or if the vapor is inhaled in a concentrated form.

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[1] Wyoming Mineral Corporation, Exploration and Mining Division. Environmental Report, Iragary Project, Johnson County, Wyoming. Lakewood, CO: Wyoming Mineral Corporation. 1977. p. 147.

[2] *Ibid.*, p. 148.

[3] *Ibid.*

Environmental hazards associated with in-situ solution mining are produced by the location of the mining process rather than by the process involved in the mining operation. For environmental hazards in the Gillette, Wyoming area, one mining company has given the harsh weather conditions of the winter season and the danger of poisonous snakes in the well fields during warm weather as potential environmental hazards.[1]

Under normal operating conditions, exposure to radiation will possibly come from two sources:[2]

1) Release of Radon-222 gas from production surge tanks and ponds, and

2) Loss of product through the scrubber stack (primarily $U_3O_8$).

Small quantities of Radon-222 gas can be released from areas where solutions are exposed to the atmosphere. In order that significant levels of daughter products are not released, the surge tanks should be enclosed and vented directly to the atmosphere to keep the concentrations of these gases down to an acceptable level.

There will be a release of $U_3O_8$ product from the dryer unit through a scrubber stack as discussed in the previous section on air emissions. These particulate radionuclides, through dispersion in the atmosphere, will be deposited in the soil, on vegetation, and in surface waters. The particulate removal system chosen should serve to minimize the environmental effects of this release by keeping the amount of release down to acceptable levels.

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[1] Wyoming Mineral Corporation, Exploration and Mining Division. Environmental Report, Irigary Project, Johnson County, Wyoming. Lakewood, CO: Wyoming Mineral Corporation. 1977. p. 149.

[2] *Ibid.*, p. 125.

Wyoming Mineral Corporation has calculated what the internal dose commitments would be for a 500,000 lb/yr yellowcake production facility located in Johnson County, Wyoming. Calculations of exposure were done for first year, 50 year, and maximum accumulated dose after 50 years to man located at the site boundary and at the nearest residence. The dispersion model used was from Turner's Workbook of Atmospheric Dispersion Estimates.[1] The dose commitment model used was from ICRP publications #2 and #10.[2,3] The results of these calculations are summarized in Tables 5-59 and 5-60.

The results of these calculations show that the internal exposure resulting from an in-situ solution mining operation would be minimal. Typical amounts of radiation that the average person is exposed to each year are:[4]

| | |
|---|---|
| Food | 0.025 rem/yr |
| Air | 0.005 rem/yr |
| Soil | 0.056 rem/yr |

Current research indicates that a person may receive up to a 25 rem dose of radiation with no detectable effect.[5]

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[1] Turner, D.B. 1970 Workbook of Atmospheric Dispersion Estimates. U.S. Public Health Service Publication No. 999-AP-26.

[2] I.C.R.P. Report of Committee on Permissible Dose for Internal Radiation. I.C.R.P., Publication No. 2, Permagon Press. 1959.

[3] I.C.R.P. Evaluation of Radiation Doses to Body Tissues From Internal Contamination Due to Occupational Exposure. I.C.R.P., Publication No. 10, Permagon Press. 1967.

[4] Johnson, T.O. Nuclear Energy Key Issue-9. Lynchburg, VA: Babcock and Wilcox, NPGD. December 1975.

[5] Glasstone, S. and A. Sesonske. Nuclear Reactor Engineering. New York, New York: Von Nostrand Reinhold Co. 1967. p. 532.

## TABLE 5-59. SUMMARY OF DOSE RATES RECEIVED FROM FACILITY BY A MAN STANDING AT A CERTAIN DISTANCE FOR A GIVEN PERIOD OF TIME

| | Maximum Annual Dose Rate |
|---|---|
| Worst Case | |
| Site Boundary (50 years) | 1.2 rem/yr |
| Site Boundary (1 year) | 0.59 rem/yr |
| Nearest Residence (50 years) | 0.0015 rem/yr |
| Nearest Residence (1 year) | 0.00076 rem/yr |
| Normal Case | |
| Site Boundary (50 years) | 0.17 rem/yr |
| Site Boundary (1 year) | 0.08 rem/yr |
| Nearest Residence (50 years) | 0.00018 rem/yr |
| Nearest Residence (1 year) | 0.00 rem/yr |

## TABLE 5-60. 50 YEAR DOSE RECEIVED AT MAXIMUM RATE

| | Dose |
|---|---|
| Site Boundary (worst case) | 60 rem |
| Site Boundary (normal case) | 8.5 rem |
| Nearest Residence (worst case) | 0.77 rem |
| Nearest Residence (normal case) | 0.009 rem |

Source: Wyoming Mineral Corporation, Exploration and Mining Division. Environmental Report, Irigary Project, Johnson County, Wyoming. Lakewood, Colo.: Wyoming Mineral Corporation, 1977, p. 134.

A summary of the annual external radiation doses received at Wyoming Mineral Corporation's Bruni, Texas solution mine is given in Tables 5-61 and 5-62. The mine at Bruni produces 250,000 lbs/yr of yellowcake. The exposure from this mining operation is low enough to allow for a 500,000 lb/yr operation to still not exceed the Nuclear Regulatory Commission's exposure limit given in 10CFR, part 20.

## TABLE 5-61. SUMMARY, 1976 - PERSONNEL DOSIMETRY RESULTS, BRUNI, TEXAS

| | |
|---|---|
| Total number of individuals monitored for entire period | = 22 |
| Total accumulated whole body exposure above background | = 70 mrem |
| Average whole body exposure | = 3.2 mrem/year/man |
| Total accumulated skin exposure | = 160 mrem |
| Average skin exposure | = 7.2 mrem/man/year |
| Present occupational (whole body) exposure limit (10CFR, P20) | = 5000 mrem/man/year |

## TABLE 5-62. AREA MONITOR RESULTS, PERIOD 10/1/76 THROUGH 1/20/77, BRUNI, TEXAS*

| Badge Number | Location | Exposure Rate |
|---|---|---|
| 2735-1003 | Outer surface of conduit at clarifier feed approximately 4' from clarifier junction | 48 mrem/year |
| 2735-1007 | On post, approximately 12-14" above ground surface, 3'-4' from clarifier underflow pond | 24 mrem/year |

*These stations consistently record the highest exposure potential as they are located near the primary external exposure source, i.e., calcium removal (radium-226).

Source: Wyoming Mineral Corporation, Exploration and Mining Division. Environmental Report, Irigary Project, Johnson County, Wyoming. Lakewood, Colo.: Wyoming Mineral Corporation, 1977, p. 127.

### 5.4.4 Social Controls for Mining

There are three categories of social controls for mining operations. First certain statutes and regulations affect the acquisition of the land itself (leasing), second controls exist for health and safety and last permits for mining and reclamation must be acquired. All three topics will be discussed below.

### 5.4.5 Obtaining Minable Lands

Leasing varies with the land ownership, hence the controls for federal, Indian, and state ownership will be discussed separately. Leasing privately owned land is discussed in Chapter 2.

As noted in Section 5.3.5a the primary method for the acquisition of uranium producing land within the public domain is the Mining Law of 1872. Procedures for filing a claim under that law have been discussed in Section 2.3, hence the discussion that follows is a description of specifics for uranium only. The sequence of activities for acquiring uranium leases on federal public domain lands is summarized in Figure 5-19. Additional figures summarize the procedure for federal acquired lands and for state lands.

Although uranium is not subject to the Minerals Leasing Act of 1920, acquired federal lands and the lands embraced within the Atomic Energy Commission (AEC) withdrawals are subject to uranium leases. As indicated in the resource description, a very small percentage of uranium resources are on federal acquired lands. BLM may issue leases on these lands under the Acquired Lands Act of 1947,[1] although at present only one lease is in operation on

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[1] 61 Stat. 913.

## Sequence of social/technological activities: Uranium (Federal public domain lands)

1

Survey and Exploration: preliminary investigation, detailed geological studies, radiometric prospecting, and exploration drilling - no BLM permit required except on lands designated as wilderness or primitive areas

2

File claim with State

3

Apply for claim patent with BLM (optional) and patent for 5 acres of land not contiguous to the claim for milling purposes

4

Where required obtain access road construction permits from Forest Service or BLM

5

Obtain water discharge permit from either EPA or State; obtain certification from State or interstate water pollution control agency showing that discharges into navigable waters meet effluent control standards Arrangements reviewrd by Corps of Engineers, USFW

6

Apply to NRC for source material license and file environmental report with NRC 9 months prior to beginning facility construction

7

Compliance with standards and regulations of EPA, NRC, MESA, OSHA, and State during mine construction

8

Mining:
  a. Open Pit
  b. Underground

Compliance with standards and regulations of EPA, NRC, MESA, OSHA, and State during production

9

Grading of ore according to radioactivity (stockpiled near mine by grade)

10

Transportation to Milling site: Open truck

11

Milling - crushing and grinding, leaching, washing (separation), purification, precipitation, separation

12

Land reclamation in accord with applicable state law

13

Mine shutdown/Abandonment

Figure 5-19.

**Sequence of social/technological activities: Uranium (Federal acquired lands)**

1

Submit lease application to Interior/BLM when deposits are known to exist; or, apply for prospecting permit from BLM if uranium deposit has not been identified

2

Issuance of lease or prospecting permit by BLM - USGS, FS review

USGS approves exploration plans

3

Obtain access road construction permits from BLM (and FS where required)

4

Survey and exploration: preliminary investigation, detailed geological studies, radiometric prospecting, and exploration drilling

USGS monitors activities

5

Obtain water discharge permit from either EPA or State; obtain certification from State or interstate water pollution control agency showing that discharges into navigable waters meet effluent control standards

Arrangements reviewed by Corps of Engineers, BSFW

6

Apply to NRC for source material license and file environmental report with NRC 9 months prior to beginning facility construction

7

File mining plan with USGS and environmental impact statement if required

Advice and assistance from BSFW

8

Compliance with standards and regulations of USGS, EPA, NRC, MESA, OSHA, and State during mine construction

9

Mining:
  a. Open pit
  b. Underground
USGS supervision;
Emission/effluents, public safety, and worker health and safety regulations enforced by USGS

10

Grading of ore according to radioactivity (stockpiled near mine according to grade)

11

Transportation to Milling site: Open truck

12

Milling - crushing and grinding, leaching, washing (separation), purification, precipitation, separation

13

Land reclamation in accord with stipulations in USGS lease

14

Application for abandonment to USGS

15

Shutdown/Abandonment

Figure 5-20.

**Sequence of social/technological activities: Uranium (State lands)**

1

Application to explore - procedure varies from state-to-state, usually first-come, first-served or competitive bid basis

2

Issuance of exploration permit from State

Preliminary investigation, detailed geological studies, radiometric prospecting, drilling

3

Obtain water discharge permit from State or EPA; comply with State, EPA air emission standards (State implementation plans subject to EPA oversight)

Obtain certification from State or interstate water pollution control agency showing that discharges into navigable waters meet effluent control standards

Arrangements reviewed by Corps of Engineers - where applicable issuance of discharge permits

4

Application to NRC for source material license and filing of environmental report with NRC 9 months prior to beginning facility construction

5

Compliance with standards and regulations per applicable State law, EPA, NRC, MESA, and OSHA during mine construction

6

Mining:
a. Open pit
b. Underground

Compliance with safety and emission standards of State, EPA, NRC, MESA, and OSHA during production

7

Grading of ore according to radioactivity (stockpiled near mine according to grade)

8

Transportation to milling site: Open truck

9

Milling:
Crushing and grinding, leaching, washing (separation), purification, precipitation, separation

10

Land reclamation according to applicable State law

11

Shutdown/Abandonment

Figure 5-21.

acquired lands. When valuable uranium mineral deposits are known to exist, the lands are leased competitively under a bonus bidding and fixed royalty system. Those lands that do not contain a known valuable uranium deposit are made available through a prospecting permit system with a preference right to lease upon discovery of a valuable deposit.[1] In the case of certain acquired lands (*e.g.*, National Forests), consent of the surface management agency (*e.g.*, Forest Service) is required prior to issuance of leases.[2]

Mineral leases are actually issued by BLM, but preparation of the terms of the lease is the joint responsibility of BLM and the U.S. Geological Survey (USGS). BLM determines whether a valuable or "workable" deposit exists according to the criteria of the "prudent man" test. USGS determines the value of the deposit, sets the financial terms of the lease, and enforces the stipulations of the lease. The Secretary of the Interior does not have the authority to cancel leases for noncompliance, leases may be cancelled only by the federal courts.

The Atomic Energy Act of 1946 gave the Atomic Energy Commission (AEC) broad powers to acquire land which contained uranium deposits through condemnation or other procedures. Except for approximately 40 square miles located primarily in western Colorado acquired between 1947 and 1966 when the primary use of uranium was for defense purposes, the Commission did not exercise its statutory authority relating to uranium land acquisition.

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[1] U.S., Congress, Senate, Committee on Interior and Insular Affairs. Federal Leasing and Disposal Policies. Hearing pursuant to S. Res. 45, A National Fuels and Energy Policy Study, 92d Cong., 2d Sess., June 19, 1972, p. 115.

[2] 43 C.F.R. 3823 (1973).

Likewise, AEC conducted no mining operations and apparently only one milling operation. In general, the Commission restricted its activities largely to purchasing uranium ores and concentrates, relying on private industry for exploration and development. Prior to 1954 the AEC issued uranium mining leases without formal regulations to govern such leases.

The Atomic Energy Act as amended in 1954 authorized AEC to "issue leases or permits for prospecting for, exploration for, mining of, or removal of deposits of (uranium) in lands belonging to the United States".[2] "This was done presumably to promote exploration and development and to solve, at the administrative level, some of the problems created by conflict with the mineral leasing laws. The Circular 7 leasing system combined elements of both the location and leasing laws".[3] However, Congress specified that AEC's leasing power should be invoked only when it is the only means of achieving private development of uranium. The law states that the leasing power is not intended to supplant the mining laws in any "normal" situation.[4] Only a few leases were actually issued and their number decreased under the terms of the Multiple Mineral Development Act which gave the lessees the option to convert their leases into mining claims. Later in 1954, Circular 7 leasing was terminated, and no leases were issued after that year.

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[1] Swenson, Robert W. "Sources and Evolution of American Mining Law," in Rocky Mountain Mineral Law Foundation, ed. The American Law of Mining. New York, N.Y.: Matthew Bender, 1973, Vol. I, p. 107.

[2] 42 U.S.C. 2097 (1970).

[3] Swenson, Robert W., *op.cit.*, p. 109.

[4] U.S., Congress, Senate, Committee on Interior and Insular Affairs. Federal Leasing and Disposal Policies. Hearing pursuant to S. Res. 45, A National Fuels and Energy Policy Study, 92d Cong., 2d Sess., June 19, 1972, p. 287.

According to legal mandate, AEC withdrawn lands may be leased by a competitive bidding and royalty system. The Commission is currently proposing to lease lands it acquired by purchase or withdrawal in western Colorado, eastern Utah, and northern New Mexico to private mining operations. The Grand Junction Operations Office (Colorado) is responsible for the administration of uranium leases on Commission-controlled lands. The disposal procedures and royalty schedules for uranium on these lands are to be determined at the discretion of the Commission. It is expected that the terms of the leases will be 5 to 10 years, renewable for an additional 5 to 10 years, and may be cancelled for noncompliance.[1]

The availability of reserved lands to mineral development varies. For example, National Forest lands reserved from the public domain are legally open to mineral development under the 1872 Mining Law. However, persons undertaking uranium development activities must comply with the rules and regulations governing the National Forests. In general, Forest Service does not encourage mineral development within its preserves and carefully scrutinizes an alleged mineral discovery to confirm whether or not it is valuable. Military reservations are generally excluded from entry although if mineral rights were established prior to reservation, these rights are recognized. It should be noted, however, that the AEC leasing authority extends to lands belonging to the U.S. and not otherwise subject to lease, such as military reservations and reservoir lands.[2]

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[1] U.S., Congress, Senate, Committee on Interior and Insular Affairs. Federal Leasing and Disposal Policies. Hearing pursuant to S. Res. 45, A National Fuels and Energy Policy Study, 92d Cong., 2d Sess., June 19, 1972, p. 287.

[2] Stoel, Thomas B., Jr. "Energy," in Dolgin, Erica L., and Thomas G.P. Guilbert, eds. Federal Environmental Law. St. Paul, Minn.: West, 1974, p. 947.

No fees are levied by the federal government on uranium deposits subject to location under the Mining Law of 1872.[1] There is no statutory provision for payment of any bonus, rental, or royalty, nor is there any Secretarial discretion to impose such fees on public domain mining claims. If the claimant patents his claim, the federal government is entitled to collect a $25 service charge (payable to BLM) and a purchase price of $5.00 per acre for a lode or vein claim and $2.50 per acre for a placer claim.[2]

Rental and royalty on uranium leases on acquired lands are generally within the discretion of the responsible agency head. Leases usually stipulate a rental charge of one dollar per acre and a royalty of seven to ten percent of the value of the minerals. AEC established a uranium purchase program in 1947 to stimulate exploration for the resource. Although the program was curtailed in 1958, it did result in the discovery and development of most of the present day uranium districts. From 1958 to 1966, exploration was conducted on a limited basis, but in 1967 the outlook for a private market in the electrical power generation industry improved so that by 1969, exploration drilling had reached an all-time high. Information on remittances to the federal government from production activities is not detailed. Aggregate estimates summarizing receipts from royalties and other landowner payments indicate that the federal government received about $500,000 per year (average) for the period 1953 to 1962. AEC received no income from uranium leases after 1962.[3]

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[1] U.S., Congress, Senate, Committee on Interior and Insular Affairs. Federal Leasing and Disposal Policies. Hearing pursuant to S. Res. 45, A National Fuels and Energy Policy Study, 92d Cong., 2d Sess., June 19, 1972, p. 118.

[2] 30 U.S.C. 29 (1970), see also 43 C.F.R. Subparts 3862 and 3863 (1973).

[3] Senate Interior Committee. Federal Leasing Policies, p. 291.

### 5.4.5b Indian Lands

A number of major uranium deposits have been developed on Indian lands (*e.g.*, the Laguna, Navajo and Spokane reservations). The Congress has enacted special laws applicable to Indian lands and therefore the Mining Law of 1872 does not pertain to this particular land category. All kinds of minerals on most tribal lands may be leased under authority of the act of May 11, 1938.[1] The principal goal of Interior regarding the development of minerals on Indian lands is to "assist the Indian landowners in deriving the maximum economic benefits from their resources consistent with sound conservation practices and environmental protection."[2]

In most cases, uranium mineral rights are leased by the tribes or individual Indians but the lease is subject to the approval of the Secretary of the Interior as trustee. Indian-owned lands are made available through a competitive lease system with advertised bids unless the Secretary of the Interior or the Commissioner of Indian Affairs authorizes private negotiations between the applicant and the landowner(s). The highest bonus bid is awarded the lease regardless of other considerations. USGS, the Indian landowners, personnel of BIA and, in some cases, their attorneys or mining consultants evaluate mineral lease offers. Rental and royalty payments are flexible and are determined according to market considerations. There is a performance requirement to spend $10 per acre per year on the development of mineral leases.[3] The Indians receive the entire income from leases on their lands.

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[1] 25 U.S.C. 3962-d.

[2] U.S., Congress, Senate, Committee on Interior and Insular Affairs. Federal Leasing and Disposal Policies. Hearing pursuant to S. Res. 45, A National Fuels and Energy Policy Study, 92d Cong., 2d Sess., 1972, p. 652.

[3] Berger, Edward B. "Indian Mineral Interest - A Potential for Economic Advancement." Arizona Law Review, Vol. 10 (Winter 1968), pp. 688.

Leases of Indian mineral land are nonrenewable and are awarded for a maximum of ten years or as long as minerals are produced in paying quantities after the ten year period. There is no limit on the number of leases an individual or corporation may hold but there is a limit of 2,560 acres per lease. Lease provisions may be amended within the term of the lease with the consent of all parties and approval by the Secretary. In addition, nearly all Indian uranium mining leases provide for a reasonable adjustment of royalty rates by the Secretary, based on market and economic conditions, at the end of the primary term and specified periods later. The Secretary also has the authority to cancel an Indian lease if violations of the terms occur.[1] Data on leases for Indian lands are not readily available.

### 5.4.5c State Lands

Most states have passed legislation providing for leasing of state-owned lands or minerals reserved from sale. The following discussion is intended to present some of the broad aspects of acquisition by private parties of rights to uranium lands owned by the western states. While all states have rather complete legislation covering all minerals, New Mexico has one of the newer and more complete systems for leasing state-owned mineral lands. Except in those cases where state legislation incorporates federal statutory provisions, minerals owned by these states are subject to state law only. In general, it is the goal of leasing statutes to "effect a policy to promote the discovery and development of the mineral resources of the state for the benefit of the public through a system of licensing on a royalty basis.[2]

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[1] U.S., Congress, Senate, Committee on Interior and Insular Affairs. Federal Leasing and Disposal Policies. Hearing pursuant to S. Res. 45, A National Fuels and Energy Policy Study, 92d Cong., 2d Sess., June 19, 1972, p. 658.

[2] Verity, Victor, John Lacy, and Joseph Geraud. "Mineral Laws of State and Local Government Bodies," in Rocky Mountain Mineral Law Foundation, ed. The American Law of Mining. New York, N.Y.: Matthew Bender, 1973, Vol. 2, p. 638.

Usually the management and disposal of state lands is located in a single agency; the lone exception being North Dakota where each state agency is allowed to lease the lands it controls. The administrative head of the agency is authorized to accept or reject lease applications. Approval of a lease may require consent from one or more state agencies. While most states have constitutional provisions authorizing the sale of state-owned lands, there has been a noticeable trend in legislation in the recent past toward reservation of minerals. Reservation policies of some states are based on retention of a fractional part (undivided) of the minerals upon sale, however, states which presently reserve minerals may have sold lands without reservation prior to passage of new legislation (*e.g.*, Colorado prior to 1917).

The manner in which minerals may be claimed affects the method of obtaining a lease. Colorado continues to use a form of location or mining claim as a preliminary step in obtaining a mineral lease, but there is a definite trend away from this kind of practice. In fact, New Mexico repealed such a statute in 1955. Likewise, the area that can be encompassed in a claim depends on specific state stipulations and, in the case of Colorado, is not specified at all. The distinction between lodes and placers made in the federal statutes as well as the recognition of extralateral rights does not receive attention in state mineral land laws and is "on the verge of extinction".[1] State laws also contain provisions for surface management, unlike federal statutes in which the claimant gains exclusive right to surface lands.

As noted above, the various methods of location are all preliminary steps toward obtaining a lease from the state.

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[1] Verity, Victor, John Lacy, and Joseph Geraud. "Mineral Laws of State and Local Government Bodies," in Rocky Mountain Mineral Law Foundation, ed. The American Law of Mining. New York, N.Y.: Matthew Bender, 1973, Vol. 2, p. 648. Although still retained by Wyoming.

Location as a rule gives the claimant a preferential right to lease the claim provided statutory requirements are fulfilled. The actual process for leasing uranium varies from state to state. Leasing may be on a preferential rights basis, a first-come first-served basis, or through competitive bidding.[1] Application for a mineral lease must be in writing and accompanied by payment of a fee to cover processing and issuance. Also, lease applications (*e.g.*, on a preferential right basis) must be filed in the time specified by statute. As a rule the leasing agency is not required to offer the land for lease and may reject an application. Mandamus may lie to compel the execution of a lease, "but is seldom successful because considerable discretion is granted the state agency charged with the management and disposition of state-owned lands".[2]

The length of the lease may vary but is within the range of three to twenty years with the right to mine thereafter as long as the specified minerals are produced in paying quantities. New Mexico provides for succeeding periods of three, two and five years at increasing rental rates. Rental rates for state mineral leases are usually fixed, and if a royalty system is in effect it is generally established through a calculation of the percentage of production. New Mexico, Wyoming, and South Dakota require bonding for faithful performance of the lease terms and Utah, New Mexico, and North Dakota stipulate posting of a bond for the protection of third persons which if forfeited may be given either directly to the third person or to the state for the benefit of the third person. Most of the states have a statutory provision for cancellation of leases for noncompliance.

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[1] For summary of state laws on leasing see Table 5-63.

[2] Verity, Victor, John Lacy, and Joseph Geraud. "Mineral Laws of State and Local Government Bodies," in Rocky Mountain Mineral Law Foundation, ed. The American Law of Mining. New York, N.Y.: Matthew Bender, 1973, Vol. 2, pp. 659-60.

Although the Colorado law does not specifically give a preferential right to a lease, judicial decision has given the locator such a priority.[1]

Included in the following tables is a summary of state statutory law for leasing of state owned uranium lands and the others are detailed compilations for each state. Although these are the procedures for leasing, it should be noted that Section 5.3.7.2 on exploration of state lands and Section 2.3 in Chapter 2 will also add classification to this section.

### 5.4.6 Health and Safety of Mining Personnel

Since Section 2.7 of Chapter 2 was devoted to a discussion of all general health and safety social controls, this section will only include a discussion of those controls specifically applicable to uranium mining. One of the more controversial aspects of uranium mine safety has been the potential exposure of underground uranium mine workers to radon gas.

Originally the Federal Radiation Council (FRC) issued guidelines for mining exposure but received criticism from labor for reflecting the interest of the nuclear industry at the expense of mining personnel.[2] In 1970, FRC functions were transferred to EPA and the Agency then became responsible for providing guidance for radon daughter exposure limits in uranium mines. The implementation and enforcement of the EPA guidelines

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[1] Verity, Victor, John Lacy, and Joseph Geraud. "Mineral Laws of State and Local Government Bodies," in Rocky Mountain Mineral Law Foundation, ed. The American Law of Mining. New York, N.Y.: Matthew Bender, 1973, Vol. 2, p. 649.

[2] Congressional Quarterly, Inc. Congress and the Nation, Vol. 3: 1969-1972. Washington, D.C.: Congressional Quarterly, 1973, p. 842.

TABLE 5-63. SUMMARY OF TERMS FOR URANIUM LEASES ON STATE LANDS

| | Duration of Lease | Preference to Lease Given | Must lease be issued under competitive bid |
|---|---|---|---|
| AZ | 20 years (renewable) | to exploration permittee | |
| CO | Not specified | | Not specified |
| MT | 10 years (renewable) | | Yes |
| NM | 3 years (renewable) | | Optional |
| ND | 5 years (continues while producing) | | Yes |
| SD | 5 years (renewable) | | Optional |
| UT | 10 years (continues while producing) | | New leases must be competitive |
| WY | 10 years (renewable) | | Not specified |

TABLE 5-64. ARIZONA URANIUM LEASE FEATURES[a]

| Item | Statutes | Summary |
|---|---|---|
| Agency | § 27-254 | State Land Department, State Land Commissioner |
| Requirements | § 27-254 | Discovery under exploration permit; Proof of valuable mineral deposit |
| Fees | | |
| Rental | § 27-234 | $15 per year for each 20 acres |
| Royalty | § 27-234 | 50% of net value of production |
| Duration | § 27-235 | 20 years, with renewal of successive 20 year terms |
| Bond | | |
| Other Information | | |

[a] Arizona Revised Statutes Annotated, 1956.

TABLE 5-65. COLORADO URANIUM LEASE FEATURES[a]

| Item | Statutes | Summary |
|---|---|---|
| Agency | § 36-1-113 | State Board of Land Commissioners |
| Requirements | | |
| Fees | § 36-1-112 | Application--50¢<br>Lease--$1.00<br>Lease service fee--$5.00 |
| Rental | § 36-1-114 | Board may adjust rentals to get maximum revenue |
| Royalty | | |
| Duration | | |
| Bond | | |
| Other Information | § 34-32-109 | See supplemental sheet for open mine permit if required |

[a] Colorado Revised Statutes, 1973.

## TABLE 5-66. MONTANA URANIUM LEASE FEATURES[a]

| Item | Statutes | Summary |
|---|---|---|
| Agency | § 81-501 | State board of land commissioners |
| Requirements | § 81-501 | These lands must be leased by competitive bids to at least fair market value |
| Fees | | |
| Rental | § 81-503 | Set by board, but not less than $2 per acre |
| Royalty | § 81-503 | Set by board, but not less than 10% |
| Duration | § 81-502 | 10 years, renewable every 5 years after that |
| Bond | | |
| Other Information | § 50-10<br>§ 50-16<br>§ 69-33 | See supplemental sheets for Strip and Underground Mining Act, Mine Siting Act, and geophysical exploration permit |
| | § 50-1704 | No person may prospect, initiate construction, or undertake pre-operation of solution extraction of uranium for 2 years (from April 8, 1975) |

[a] Revised Codes of Montana, 1947. This is also the procedure for uranium exploration in Montana.

## TABLE 5-67. NEW MEXICO URANIUM LEASE FEATURES[a]

| Item | Statutes | Summary |
|---|---|---|
| Agency | § 7-9-17 | Commissioner of Public lands |
| Requirements | | |
| Fees | § 7-9-21.1 | $10 |
| Rental | § 7-9-22 | Rent to be set by commissioner but not less than 5¢ per acre during primary and not less than 50¢ per acre secondary--con'd |
| | § 7-9-31 | Maximum are in lease - 16 sections |
| Royalty | § 7-9-23 | Not less than 5% or gross plus not less than 5% of all bonuses earned by lessee |
| Duration | § 7-9-21 | Primary term 3 years, a 2-year extension available but rent is 10 times as much per year. Secondary term for production allowed |
| Bond | § 7-9-25 | Bond set by commissioner but not less than $5,000 for surface repair |
| Other Information | § 7-9-34 | Commissioner may use competitive bidding |
| | § 7-9-19 | In 1955 New Mexico ceased to issue the prospecting permit and all exploration must come under lease procedures above |

[a] New Mexico Statutes, 1953. This is also the procedure for uranium exploration in New Mexico.

TABLE 5-68. NORTH DAKOTA URANIUM LEASE FEATURES[a]

| Item | Statutes | Summary |
|---|---|---|
| Agency | § 38-11-03 | All agencies of the state are authorized to lease, but Board of University and School Land established standards, policies, terms, conditions, rules, and regulations for such activities. |
| Requirements | | |
| Fees | | |
| Rental | § 38-11-02 | Set by Board of University and School Land |
| Royalty | § 38-11-07 | Set by Board of University and School Land |
| Duration | § 38-11-03 | Set by Board of University and School Land |
| Bond | § 38-15-03 | The Industrial Commission may require a bond to satisfy conflicts between mining or oil and gas developers on same land. |
| Other Information | § 38-16 | The State Soil Conservation Committee requires a report of operation annually if it is a surface mine. |

[a] North Dakota Century Code, 1960, as amended. This is also the procedures for uranium exploration in North Dakota.

TABLE 5-69. SOUTH DAKOTA URANIUM LEASE FEATURES[a]

| Item | Statutes | Summary |
|---|---|---|
| Agency | § 5-7-1 | Commissioner of school and public lands |
| Requirements | § 5-7-13 | A reclamation plan |
| Fees | § 5-7-12 | $25 for application |
| Rental | | |
| Royalty | § 5-7-12 | Fixed by Board of School and Public lands, but not less than 5% |
| Duration | § 5-7-12<br>§ 5-7-12 | Nor more than five years, with renewal available for five year terms |
| Bond | § 5-7-13 | Required for payment of royalties |
| Other Information | § 5-7-13 | Amount of bond for no. 7 above at discretion of commissioner |
| | § 45-7A-3 | A report of any exploratory well drilled must be sent to Department of Natural Resources (will be kept confidential) |
| | § 45-7A-2 | Such wells must be capped, sealed, or plugged |
| | § 5-7-2 | This section specifically exempts coal and uranium from a required lease by competitive bidding |
| | § 5-7-11 | This section says the permittee may apply for a license (lease). (But says nothing of preference to permittee) |
| | § 45-6A-16 | This section exempts state lands from the requirement of a surface mining permit (fee-$50) issued by the state conservation commission |

[a] South Dakota Compiled Laws, 1967.

## TABLE 5-70. UTAH URANIUM LEASE FEATURES[a]

| Item | Statutes | Summary |
|---|---|---|
| Agency | § 65-1-18 | State Land Board |
| Requirements | | |
| Fees | § 65-1-24 | 15¢ per acre |
| Rental | § 65-1-18 | Not less than 50¢ per acre per year nor more than $1.00 per acre per year |
| Royalty | § 65-1-18 | Not more than 12½% of gross |
| Duration | § 65-1-18 | Not less than 10 years and for so long as producing |
| Bond | § 65-1-90 | Required only to reinstate lease after failure to pay for damages to surface |
| Other Information | § 65-1-90 | Amount of bond in item no. 7 |
| | § 40-8-13<br>§ 40-8-14 | If this is a mining operation (surface) the developer must submit a plan of reclamation and before operations start also execute a bond, for surface damage. The Board of Oil, Gas, and Mining controls this aspect. The Board determines the amount of bond |
| | § 40-6-5 | The Board of Oil, Gas and Mining has the authority to require:<br>(a) security (for plugging)<br>(b) notice of intent to drill<br>(c) filing of a well log (for any drilling) |
| | § 65-1-45 | Newly acquired lands and lands with an expiring lease must be let through competitive bids, all others leased to first applicant. |

[a] Utah Code Annotated, 1953.

TABLE 5-71. WYOMING URANIUM LEASE FEATURES[a]

| Item | Statutes | Summary |
|---|---|---|
| Agency | § 36-74 | Board of land commissioners, Commissioner of public lands |
| Requirements | | |
| Fees | § 36-42 | Fee for filing a lease application is $15 |
| Rental | | |
| Royalty | | |
| Duration | § 36-74 | Not more than 10 years, with preferential right to renew for 10 year periods |
| Bond | | |
| Other Information | § 36-74 | The agency above has authority to set rates and terms in its rules and regulations within confines of specific statutes noted above |

[a] Wyoming Statutes of 1957.

are within the authority of Labor, specifically the Mine Safety and Health Administration (MSHA). The mandatory limits for radon daughter exposures are no more than 4 working level months (WLM)[1] exposure during any calendar year, no exposures greater than 1.0 WL, and individual exposure level records required for persons working in any area with levels greater than 0.3 WL.[2]

### 5.4.7 Mining Permits and Reclamation

Not all mining on federal lands is controlled by permit nor is all of it subject to reclamation. Below is discussed the controls in the specific areas.

#### 5.4.7a Federal Regulation

As noted in the section on making lands available, a high percentage of uranium is found on public domain lands. Since in this case uranium is a location-patent mineral, the mining laws in effect give the locator possessory rights to the claim. As a result, federal controls governing land use and land reclamation for uranium mining activities on the public domain are lacking in some areas. According to the Mining Law of 1872, no permit is required for mining on these lands, although permits are required for the construction of access roads to mining sites on land administered by BLM and the Forest Service.

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[1] "Working level" (WL) is a measure of level of radiation due to products of radioactive decay of radon. It is set at an emission of 1.3 x $10^5$ million electron volts of alpha rays per liter of air. Inhalation of air containing a radon daughter concentration of 1 WL for 173 hours results in an exposure of 1 working level month (WLM). 30 C.F.R. 57.2.

[2] 30 C.F.R. 57.5-37 to -40.

In terms of protection of nonmineral resources on the public domain, the surface management agency is responsible for protecting other resources which may be adversely affected by mining operations. For example, uranium production is subject to certain regulations on public domain lands administered by the Forest Service.[1]

The Mining Law of 1872 does not provide for federal control of land reclamation or environmental impacts. Regulations promulgated by Interior for reclamation of public lands exempt uranium mining.[2] In cases where federal control is lacking, particularly in the area of land reclamation on the public domain, Colorado and Wyoming have passed laws requiring the restoration of lands disturbed by mining operations. These state laws are applicable to mining operations on the public domain.

On federally acquired lands the BLM may formulate requirements for land reclamation and the protection of nonmineral resources to be incorporated into the terms of the lease. The Forest Service and the Bureau of Sport Fisheries and Wildlife (BSFW) may have input into this process.[3] Before extraction begins, a mining plan must be filed with USGS, and this plan may contain provisions for land reclamation and the protection of other nonmineral resources. USGS decides whether or not to issue an environmental impact statement on the proposed mining operation. The agency is also responsible to supervising mining operations conducted on acquired lands.

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[1] Doub, William O., *et al.* Federal Energy Regulation: An Organizational Study. Washington, D.C.: Government Printing Office, 1974, p. H-20.

[2] 43 C.F.R. Subtitle A, 23.2a.

[3] Doub, William O., *et al.*, *op.cit.*, p. H-21.

On Indian lands provisions for land reclamation and the protection of other resources may be incorporated into the terms of the lease, as noted earlier. In addition, provisions for land reclamation and other environmental provisions must be out-lined in the leasee's mining plan which is subject to approval by USGS. Conformity with lease and mining plan provisions is subsequently monitored by the Geological Survey.[1] The mining operator is also required to file a performance bond on Indian lands.

While most of the manufacturing operations that comprise the nuclear fuel cycle are subject to licensing and regulation by the Nuclear Regulatory Commission (NRC), uranium mining is an exception. NRC does have the authority to issue mining permits on federal lands, but for the most part has only exercised this authority on what were AEC withdrawn lands. However, the NRC considers the environmental effects of uranium mining pursuant to its licensing authority for closely related milling operations. The NRC Director of Regulation requires that environmental impact statements filed for milling operations include the impact of mines owned and operated in conjunction with the mill.

The regulation of emissions and effluents from mining operations falls within the auspices of a number of agencies. In general, EPA or states with EPA approved programs set standards for water and air quality and have responsibility for the enforcement of these standards. A uranium mining operation must obtain a water discharge permit from either EPA or a state with an EPA approved water quality program. In some cases, the Corps of Engineers reviews EPA discharge permits to assess the potential impact of the activity on navigation waters.[2]

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[1] 25 C.F.R. Chapter I, Subchapter P, 177.7.

[2] Doub, William O., *et al.* Federal Energy Regulation: An Organizational Study. Washington, D.C.: Government Printing Office, 1974, p. H-21.

EPA has established effluent limitations for uranium mines as point sources. These are indicated in Table 5-72 for existing and new sources. These limitations may be exceeded as a result of a storm which is not likely to occur any more frequently than once in 25 years.[1]

On acquired lands where uranium mineral rights are leased (*i.e.*, deposits are known to exist), BLM may require certain effluent standards to be met as a condition of the lease. The Forest Service and the Bureau of Sport Fisheries and Wildlife may have input into this process.[2] USGS supervises uranium mining operations to insure compliance with agency environmental stipulations in addition to enforcing its own regulations which are designed to minimize pollution.[3]

### 5.4.7b State Regulation

Some western states have attempted to fill the void in uranium land reclamation making their state laws applicable to all lands within the state including the public domain. In particular Colorado and Wyoming have done so. Although other states have reclamation laws they may or may not be applicable to federal-public domain lands.

Although Colorado has a relatively weak strip mining law, a new state law went into effect in 1974 giving the state control over development activities of statewide interest (H.B. 1041).

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[1] Federal Register 40, 215, p. 51745, Nov. 6, 1975.

[2] Doub, William O., *et al.* Federal Energy Regulation: An Organizational Study. Washington, D.C.: Government Printing Office, 1974, p. H-21.

[3] U.S., General Services Administration, National Archives and Records Service, Office of the Federal Register. United States Government Manual 1973/74. Washington, D.C.: Government Printing Office, 1973, p. 272.

TABLE 5-72. EFFLUENT LIMITATIONS FOR URANIUM MINES

| Effluent | Existing Sources[a] | | New Sources[b] | |
|---|---|---|---|---|
| | Max for any one day | Avg. for 30 days | Max for any one day | Avg. for 30 days |
| TSS | 30 | 20 | 30 | 20 |
| Cd | 0.10 | 0.05 | 0.10 | 0.005 |
| Zn | 0.2 | 0.1 | 0.2 | 0.1 |
| As | 0.2 | 0.1 | 0.2 | 0.1 |
| Ra 226[c] | 10 | 3 | 10 | 3 |
| U | 4 | 2 | 4 | 2 |
| COD | 100 | 50 | 100 | 50 |
| Mo | 2.0 | 1.0 | - | - |
| V | 10 | 5 | - | - |
| pH | within the range 6.0 to 9.0 | - | within the range 6.0 to 9.0 | - |

[a] 40 CFR 440.53 (a) (1)

[b] 40 CFR 440.55 (a) (1)

[c] Values in picocurie per liter

In addition, the legislature enacted another bill (H.B. 1034) in 1974 to clarify the full zoning and planning controls now available to localities. New Mexico, although it has no statewide land use policy, does have a strip mining law. The Conservation and Land Use Study Commission of Wyoming has drafted a state land use planning act which is being considered by the legislature. The Utah Land Use Act, providing for designation of and planning for critical environmental areas, was passed by the legislature in 1974.

## 5.5 URANIUM MILLING

The basic purpose of the milling process is to extract the $U_3O_8$ from the uranium ore and concentrate it into "yellowcake" (which contains about 90 percent $U_3O_8$). There are several operational uranium milling facilities in the U.S. Currently, uranium mills have milling capabilities from 400 to 7,000 tons of ore per day.[1] The milling module described in this section processes the ore from the surface and underground uranium mines described in the mining section. The rate of mill input assumed in the discussion of milling technology is 1200 tons/day (440,000 TPY). The ore is assumed to contain 0.2 percent $U_3O_8$. The recovery at the mill is assumed to be 93 percent of $U_3O_8$ input. Upon this basis, the mill produces 4500 lb/day (800 ton/year) of yellowcake containing 4200 lb/day (740 ton/year) $U_3O_8$.

### 5.5.1 Technology

Extraction of uranium from the ore involves both mechanical and chemical processes, with the chemical process being the core of the milling operation. There are two chemical processes that are used by U.S. uranium mills for extracting uranium from ore, the acid leach process and the alkaline carbonate leach process.[1,2,3,4,5,6,7] Selection of the leaching process is dependent on the physical and chemical properties of the ore, with the main consideration being the lime content of the ore.[8] The acid leaching process is suitable when the ores have a lime content on the order of 12 percent of less.[9] The alkaline carbonate leaching process is suitable when the ores have higher lime content. The acid leaching process does not dissolve radium as readily as the alkaline leaching process.[10]

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[1] ERDA. Statistical Data of the Uranium Industry. Grand Junction, Colorado: U.S. Energy Research and Development Administration, Grand Junction Office, January 1, 1977, p. 102.

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[1] Battelle, Pacific Northwest Laboratories. Data for Preliminary Phase of the Environmental Quality Information and Planning System (EQUIPS). BNWL-B-141, Richland, Wash., 1971.

[2] Clark, Don A. State-of-the-Art - Uranium Mining, Milling, and Refining Industry, EPA 660/2-74-038. Rob't S. Kerr Environmental Research Lab., Ada OK, 1974.

[3] Caropreso, Frank E. and Badger, William P. "Hydrogen Peroxide Precipitation of Uranium at the Atlas Minerals Uranium Mill," Trans., Soc. Mining Engrs., AIME 254 (4), 281, 1973.

[4] Geier, Harold. "Uranium Ore Treatment," Megallges, A. G., Rev. Activ., N.S. No. 13 (1970), 29.

[5] Humble Oil and Refining Co., Minerals Dept. Highland Uranium Mill, Converse County, Wyoming, Applicant's Environmental Report, Houston, Tex., 1971.

[6] Nuclear Assurance Corp. U.S. Uranium. Economics and Technology, NAC-1, Atlanta, Ga.

[7] Rosenbaum, J. B. and George, D. R. "Cost Reductions in Ion Exchange Processing of Uranium Ores," Symposium on the Recovery of Uranium from Its Ores and Other Sources, Sal Paulo, Aug. 1970, Proceedings, Vienna, International Atomic Energy Agency, 1971, pp. 297 ff.

[8] Battelle, Pacific Northwest Laboratories. Data for Preliminary Demonstration Phase of the Environmental Quality Information and Planning System (EQUIPS), BNWL-B-141, Richland, Wash., 1971.

[9] Clark, Don A. State-of-the-Art - Uranium Mining, Milling, and Refining Industry, EPA 660/2-74-038, Rob't. S. Kerr Environmental Research Laboratory, Ada, Ok., 1974.

[10] U.S. Atomic Energy Commission. Environmental Survey of the Nuclear Fuel Cycle, WASH-1237, Springfield, Va.: NTIS, 1972.

As a consequence, the acid leaching process discharges more radium with the tailing thereby creating solid wastes with slightly increased radioactivity.

In the U.S., most uranium mills use the acid leaching process. As reflected in Table 5-73, only four of the sixteen uranium mills in operation employ the alkaline leaching process.

Several steps are involved in removing uranium from ore during uranium milling operations. To illustrate the milling operations, a block diagram of the acid leaching process is shown in Figure 5-22. The uranium mill subsequently described is similar to a mill proposed by Humble Oil and Refining Company to be operated in Converse County, Wyoming and represents the process predominantly used in the U.S.[1]

The first step in the milling process is ore preparation. Characteristics of concern include size, hardness, uranium content, clay content, and moisture content. With all ore processing plants, some "average ore" must be defined and the design based on it. A design based on the "worst ore" will be extremely expensive to build and will have excess capacity most of the time. Conversely, if the "best ore" is assumed, the plant will be less expensive to build but will not have adequate capacity most of the time. The same holds true if any single characteristic of the ore is considered.

The blending and storage yard will allow blending of ore from various parts of the pit to maintain steady, average characteristics. Up to 50 days' ore requirements can be placed

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[1] Humble Oil and Refining Company. Environmental Report, Highland Uranium Mill, Converse County, Wyoming, Applicants Report to the Atomic Energy Commission. Houston, Texas: Humble Oil and Refining, July 1971.

## TABLE 5-73. URANIUM MILL PROCESS METHODS AS OF 1/1/77

| State and Company | Plant Location | Mill Process |
|---|---|---|
| Colorado: | | |
| Cotter Corporation | Canon City | AlK, C-ppt |
| Union Carbide Corporation | Unravan | AL, CCD, IX |
| New Mexico: | | |
| The Anaconda Company | Grants | AL, BRIP |
| Kerr-McGee Corporation | Grants | AL, CCD, SX |
| Sohio-Reserve Oil[a] | Cebolleta | AL[b] |
| United Nuclear-Homestake Partners | Grants | AlK, C-ppt |
| Texas: | | |
| Conoco-Pioneer | Falls City | AL, CCD, SX[c] |
| Utah: | | |
| Atlas Corporation | Moab | AlK, BRIP |
| Rio Algom Corporation | La Sal | ALK[b] |
| Washington: | | |
| Dawn Mining Company | Ford | AL, IX[b] |
| Wyoming: | | |
| Federal American Partners | Gas Hills | AL, ELUEX, CRIP |
| Union Carbide Corporation | Gas Hills | AL, CRIP |
| Utah International Inc. | Gas Hills | AL, CCD, ELUEX |
| Utah International Inc. | Shirley Basin | AL, CCD, ELUEX |
| Western Nuclear Inc. | Jeffrey City | AL, ELUEX, CRIP |
| Exxon Company | Powder River Basin | AL, CCD, SX[d] |

Source: Nuclear Assurance Corp. U.S. Uranium, Economics and Technology, NAC-1. Atlanta, GA. Nuclear Assurance Corp. p. VIII-6.

[a] ERDA. Statistical Data of the Uranium Industry. Grand Junction, Colorado: U.S. Energy Research and Development Administration, Grand Junction Office. January 1, 1977. p. 102.

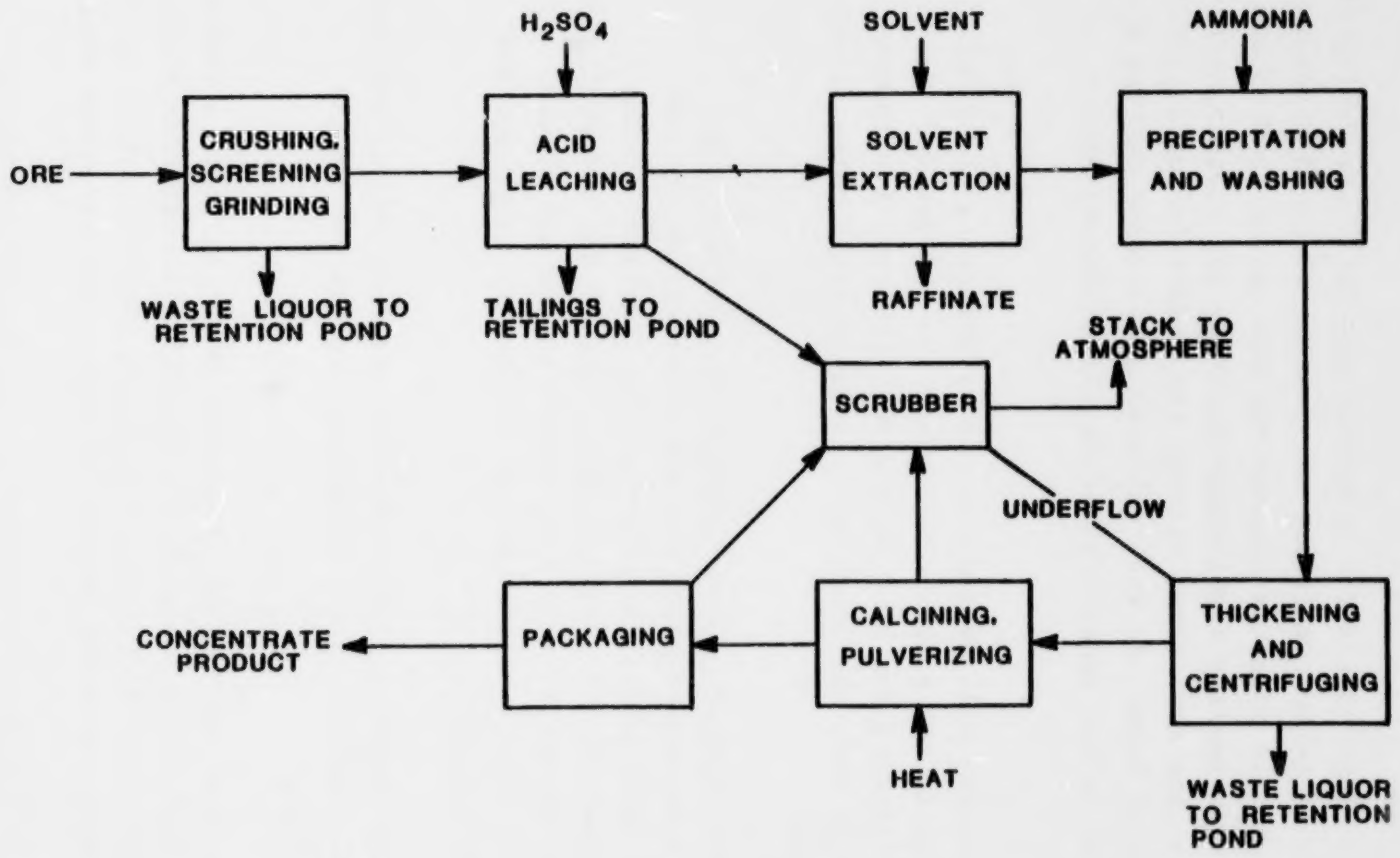
[b] Mining Information Services, Engineering and Mining Journal. 1977 E/MJ International Directory of Mining and Mineral Processing Operations. New York, NY. Mining Information Services of the McGraw-Hill Mining Publications. 1977. Sect. 2A.

[c] Kullus, M.F. Environmental Aspects of Uranium Mining and Milling in South Texas. Houston, TX. U.S. Environmental Protection Agency, Houston Branch. 1975. p. V-GA.

[d] Exxon Company, U.S.A. Application for Amendment to Source Material License SUA-1139 for Solution Mining of Uranium, Supplemental Environmental Report. Houston, TX. Exxon Company. 1977. Appendix I, p. 26.

### Abbreviations

| | | | |
|---|---|---|---|
| ALK | - Alkaline Leach | CRIP | - Continuous Resin in Pulp |
| AL | - Acid Leach | ELUEX | - Rip or IX with H SO solution |
| CCD | - Countercurrent decantation | IX | - Column Ion Exchange |
| C-ppt | - Caustic precipitation | SX | - Solvent Extraction |
| BRIP | - Basket Resen in Pulp | | |



ORE
CRUSHING, SCREENING GRINDING
WASTE LIQUOR TO RETENTION POND
$H_2SO_4$
ACID LEACHING
TAILINGS TO RETENTION POND
SOLVENT
SOLVENT EXTRACTION
RAFFINATE
AMMONIA
PRECIPITATION AND WASHING
SCRUBBER
STACK TO ATMOSPHERE
UNDERFLOW
THICKENING AND CENTRIFUGING
WASTE LIQUOR TO RETENTION POND
CALCINING, PULVERIZING
HEAT
PACKAGING
CONCENTRATE PRODUCT

Figure 5-22. Uranium Mill Block Diagram.

Source: U.S. Atomic Energy Commission. Environmental Survey of the Nuclear Fuel Cycle, WASH-1237. Springfield, in the yard. This will allow a further benefit - the drying of the ore from 15 percent moisture as mined to 10 to 12 percent moisture. At this moisture content the ore can be handled and crushed without causing significant sticking and clogging problems, and, at the same time, without the generation of significant amounts of dust. As with all open areas, some dusting will result. This is not considered to be a significant health problem.[1]

The blending will be carried out by directing the trucks from the mine to the proper pile to achieve the desired blend. Additional blending can be achieved when the ore is withdrawn from the piles with the front-end loader as it is being fed to the ore hopper.

The next segment of ore preparation is crushing and grinding. Size reduction of the ore is necessary for two reasons; 1) small particles offer greater exposure of the uranium mineral to the leaching agent, and 2) the ore particles must be fine enough so that they can be pumped and flowed through pipes and process equipment without settling out and clogging the system.

An apron feeder will withdraw ore from the hopper and feed it out a belt conveyor which transfers the ore out to the crusher building.

In the crushing process, the uranium ore is first screened in a three inch vibrating grizzly. Material larger than three inches is separated and conveyed to a two impeller impact crusher. Crushed material from the crusher is mixed with the minus three inch material from the grizzly and then ground to small particles in a wet rod mill. The ground ore is pumped, in slurry form, from the rod mill to the leaching process.

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[1] Catlin, Robert J. "Uranium Mining Health and Safety," presented at the Topical Conference on Nuclear Public Information, Pal Harbour, Florida, March 22, 1971.

The dust from the ore preparation is controlled by two dust collection systems, one in the crushing area and the other in the fine ore bin area. They are fan-powered wet systems designed to operate at a dust concentration of 8 grains of minus 10 micron sandstone dust per cubic foot. The collection efficiencies are greater than 95 percent.

Leaching is the process by which the uranium minerals are dissolved from the bulk of the valueless sandstone. The process devised for treating the ore utilizes heat to increase the reaction rate of the leaching agents. Sulfuric acid and sodium chlorate are added at the rates of 40 pounds and 1 pound per ton of ore.

The leaching process continues over 8 hours as the slurry flows by gravity through the series of 8 mechanically agitated holding tanks. All of the soluble uranium (more than 95 percent of the total uranium) has at this point been placed in solution.

The recovery of uranium from the leach solution is accomplished in four sequential steps. The first involves the separation of the dissolved uranium from the insoluble waste material or tailing. The second is the concentration of uranium by extraction from the leach solution into an organic phase and then returning it to another aqueous phase. The third step is the precipitation of the uranium from solution as yellowcake. The final step is drying the yellowcake product.

A five-stage countercurrent decantation (CCD) process will be used to separate the uranium solution from the insoluble solid waste residue. The final product from the decantation process is a relatively clear aqueous solution containing the $U_3O_8$ without the undissolved solids. The $U_3O_8$ is then removed from this solution by solvent extraction.

Solvent extraction is an ion exchange process which uses a liquid ion exchange reagent dissolved in a kerosene organic phase. The ion exchange reagent, a tertiary amine, is very soluble in kerosene but quite insoluble in water. When the organic phase is mixed with the aqueous uranium solution, sulfate ion from the organic phase is exchanged for a uranium ion from the aqueous phase. Four serial stages of solvent extraction are used. After the uranium has been removed, this aqueous solution is recycled to the CCD circuit to dissolve additional uranium.

The organic phase, which now contains the uranium, is pumped to a four-stage stripping circuit where the uranium ions are stripped from the organic phase with a concentrated ammonium sulfate solution. The uranium free organic phase is recycled to the solvent extraction circuit. The aqueous phase, laden with highly concentrated uranium is pumped to the precipitation process.

Precipitation involves adding anhydrous ammonia to the uranium solution to precipitate yellow ammonium uranium oxide, chemically $(NH_4)_2 U_2O_7$. This yellow precipitate is separated from the solution by gravity settling a series of two thickeners. The second thickener underflow is pumped to a continuous solid bowl centrifuge for further washing and dewatering. The centrifuge discharge (yellowcake) goes to the drier.

The yellowcake must have almost no contained moisture to meet specifications. This is accomplished by heating the discharge of the centrifuge to about 600°F in a six-hearth roaster.

The roaster off-gas with its entrained dust load is treated in a wet dust-collecting system. Yellowcake dust produced during the subsequent packaging operation is collected through the same system. The dust loading of the gas entering the system is estimated at .73 grains/cubic foot, with most particles minus 10 microns. The dust content of the discharge gas is .005 grains/cubic foot. The system assures that people within and outside of the restricted area are not exposed to unsafe conditions.

The dried yellowcake is pulverized using a single impactor hammer mill and stored in a hopper. A hose-tubing connection is made to the 55-gallon drums in which the product will be stored and shipped. The connection is dust tight, and the air displaced during the filling of the drum is exhausted through the previously mentioned dust collection system.

The uranium mill is designed so that during normal operation and all foreseeable emergency conditions, no solution or fluid of any kind can escape the process. All spills are pumped back to the process or to the tailing when the emergency is over. This is accomplished by careful planning of floor grades and building walls so that there is adequate volume to contain spills within the buildings.

### 5.5.2 Input Requirements

The inputs to a 1200 ton/day uranium ore milling facility are considered in the following sections. These inputs include labor, materials and equipment, capital expenditures, water, land, and a source of energy.

### 5.5.2a Manpower Requirements

There are two labor phases required of all facilities - construction and operation. Exxon has estimated the personnel necessary to construct and operate a mill capable of processing 2500 tons of raw ore per day.[1] Tables 5-74 and 5-75 present the proposed personnel for construction and operation of such a mill.

Construction is assumed to be a 1-shift, 40-hour week operation. These same figures can be used as a high estimate of the manpower required to construct a 1200 ton/day mill. With this estimate, the construction of the 1200 ton/day mill should take less than the three year period proposed for the 2500 ton/day mill.

Exxon has estimated that a labor force of 77 people would be required to operate their 2500 ton/day facility. Rocky Mountain Energy Co. has estimated a total mill-work force of 75 people for its 1000 ton/day mill.[2] The similarities of these two estimates indicate that among commercial scale processing mills, size does not greatly affect personnel requirements. Therefore we will assume the personnel requirements given for operating Exxon's 2500 ton/day mill would probably also serve as a good estimated for the 1200 ton/day mill. A typical mill will operate for about 10 years.

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[1] Planning Support Group Bureau of Indian Affairs. Uranium Exploration, Mining and Milling Proposal, Navajo Indian Reservation, New Mexico, Volume I. Billings, Montana: Bureau of Indian Affairs, Dept. of the Interior, June 1976, p. 1.8.

[2] Dames and Moore. Environmental Report, Bear Creek Project, Converse County, Wyoming, For Rocky Mountain Energy Company. Denver, Colorado: Rocky Mountain Energy Company, 1975, p. 5-47

TABLE 5-74. MANPOWER RESOURCES REQUIRED FOR CONSTRUCTION OF A 2500 TON/DAY URANIUM MILLING FACILITY

| Skill | Quantity |
|---|---|
| Supervisors and staff | 20 |
| Contract special skills | 7 |
| Pipe fitters | 40 |
| Steel workers | 20 |
| Millwrights | 5 |
| Electricians | 15 |
| Carpenters | 15 |
| Concrete finishers | 2 |
| Operating engineers | 9 |
| Mechanics | 3 |
| Laborers | 15 |
| | 151 |

Source: Planning Support Group, Bureau of Indian Affairs. Uranium Exploration, Mining and Milling Proposal, Navajo Indian Reservation, New Mexico. Volume I. Billings, Montana. Bureau of Indian Affairs, Department of the Interior. June, 1976. p. 1.8.

TABLE 5-75. MANPOWER RESOURCES REQUIRED FOR OPERATING A 2500 TON/DAY URANIUM MILLING FACILITY

| Skill | Quantity |
|---|---|
| Management and staff* | 15 |
| Laboratory technicians* | 6 |
| Operations foremen** | 4 |
| Operations technicians** | 28 |
| Maintenance foremen** | 2 |
| Maintenance technicians** | 14 |
| Instrument technicians** | 4 |
| Warehousemen** | 4 |
|  | 77 |

* Required for a 1-shift, 5-day week

** Total required for the continuous 7-day week operation of the mill. About one-fourth of the personnel would be working at any one time.

Source: Planning Support Group, Bureau of Indian Affairs. Uranium Exploration, Mining and Milling Proposal, Navajo Indian Reservation, New Mexico. Volume I. Billings, Montana. Bureau of Indian Affairs, Department of the Interior. June, 1976. p. 1.8.

### 5.5.2b Materials and Equipment

Table 5-76 lists the major materials required to construct a 1200 ton/day uranium ore milling facility. This data was extracted from data contained in "The Energy Supply Planning Model."[1]

Table 5-77 lists the major materials consumed per day in order to operate a 1200 ton/day mill. These numbers are from data presented for the 1000 ton/day Bear Creek uranium mill.[2]

The equipment required for the operation of a mill, in addition to the milling facility itself, is given in Table 5-78. This equipment requirement was estimated for a 2500 ton/day mill but is a good estimate for a 1200 ton/day mill because of the economy of size.

### 5.5.2c Economics

Dames and Moore have issued a report which provides an estimate of mill capital construction costs. These costs were reported in 1975 dollars.[3] Table 5-79 presents the capital construction costs interpolated from the three mill capacities mentioned in the report. These costs have been adjusted to 1977

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[1] Carasso, M., et al. Energy Supply Model, Computer Tape. San Francisco, Calif.: Bechtel, 1975.

[2] Nuclear Regulatory Commission. Operation of Bear Creek Project, Rocky Mountain Energy Company, Docket No. 40-8452. Washington, D.C.: Nuclear Regulatory Commission, Office of Nuclear Materials Safety and Safeguards, June 1977, p. 3-26.

[3] Lootens, D. J. Uranium Production Methods and Economic Considerations. Park Ridge, Illinois: Dames and Moore, 1975.

TABLE 5-76. SELECTED MAJOR MATERIALS REQUIRED FOR CONSTRUCTION OF A 1200 TON/DAY URANIUM ORE MILLING PLANT

| Resource | Number |
|---|---|
| Ready mixed concrete (tons) | 6,000 |
| Piping (tons) | 110 |
| Structural steel (tons) | 140 |
| Reinforcing bars (tons) | 140 |
| Pumps & drives (100HP) (items) | 28 |
| Pumps & drives (100HP) (tons) | 35 |

Source: Curusso, M., *et al.* Energy Supply Model, computer tape. San Francisco, California. Bechtel, 1975. p. 3-26.

### TABLE 5-77. ESTIMATED MATERIAL REQUIREMENTS FOR A 1200 TON/DAY URANIUM MILLING FACILITY

| Material | Rate of consumption | Circuit inventories |
|---|---|---|
| Water | 288,000 gal/day | 780,000 gal including storage |
| $H_2SO_4$ | 60,000 lb/day | 1,056,000 lb including storage |
| $NH_3$ | 960 lb/day | - |
| $NaClO_3$ | 4,800 lb/day | - |
| Flocculents | 3,000 lb/day | - |
| Kerosene | 36 gal/day max | 48,000 gal |
| Amine | 12 lb/day max | 10,080 lb |

Source: Nuclear Regulatory Commission. Operation of Bear Creek Project, Rocky Mountain Energy Company, Docket No. 40-8452. Washington, D.C. Nuclear Regulatory Commission. Office of Nuclear Materials Safety and Safeguards. June 1977. p. 3-26.

TABLE 5-78. EQUIPMENT REQUIRED FOR OPERATION OF A 2500 TON/DAY URANIUM MILLING FACILITY

| Unit | Quantity |
|---|---|
| Front-end loader, 4 cu yd, diesel | 1 |
| Front-end loader, 1/4 cu yd, diesel | 1 |
| Forklift, 3,000 lb, gasoline | 1 |
| Boom truck, 5-ton, gasoline | 1 |
| Trucks, 3/4-ton, gasoline | 2 |

Source: Planning Support Group, Bureau of Indian Affairs. Uranium Exploration, Mining and Milling Proposal, Navajo Indian Reservation, New Mexico. Volume I. Billings, Montana. Bureau of Indian Affairs. Department of the Interior. June, 1976. p. 1.7.

TABLE 5-79. URANIUM ORE PROCESSING MILL CAPITAL CONSTRUCTION COST ESTIMATES (1977 DOLLARS) - 1200 TON/DAY MILL

| Item | Mill Capital Cost ($) |
|---|---|
| Unloading, crushing, sampling | 1,520,000 |
| Grinding | 580,000 |
| Leaching | 920,000 |
| Classification, purification | 1,450,000 |
| Precipitation, filtration | 310,000 |
| Tailings disposal | 77,000 |
| General facilities and utilities | 5,060,000 |
| Engineering and field expense | 1,400,000 |
| Contractor feed, contingency | 575,000 |
| TOTAL COST | 11,892,000 |

Source: Lootens, D. J. Uranium Production Methods and Economic Considerations. Park Ridge, Illinois: Dames & Moore, 1975.

dollars based upon cost index data from Chemical Engineering magazine.[1,2]

Operating costs interpolated from three sizes of uranium milling operations are shown in Table 5-80. Dames and Moore reported total operating cost estimates for a mill.[3] This total cost has been broken down into four components - supplies 59%, labor 30%, other 6%, and utilities 5%.[4] Costs have been adjusted to 1977 dollars using cost index data from Chemical Engineering magazine.[5,6]

TABLE 5-80. OPERATING COST ESTIMATE FOR URANIUM MILLING OPERATION (1977 DOLLARS) - 1200 TON/DAY MILL

| Component | Mill Operating Cost ($/Ton) |
|---|---|
| Supplies | 6.06 |
| Labor | 3.33 |
| Other | .71 |
| Utilities | .62 |
| TOTAL COST | 10.72 |

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[1] Chemical Engineering. "Economic Indicators." Chemical Engineering, Vol. 82 (Dec. 22, 1975), p. 116.

[2] *Ibid.*, Vol. 89 (Dec. 5, 1977), p. 7.

[3] Lootens, D. J., Uranium Production Methods and Economic Considerations. Park Ridge, Illinois: Dames and Moore, 1975.

[4] Long, E. A. and W. R. Archibald. "Innovative Systems for the Recovery of Uranium." 1975 Mining Yearbook. Denver, Colo.: Colorado Mining Association, 1975, p. 115.

[5] Chemical Engineering. *op.cit.*, Vol. 82 (Dec. 22, 1975), p. 116.

[6] Chemical Engineering. *op.cit.*, Vol. 89 (Dec. 5, 1977), p. 7.

### 5.5.2d Water Requirements

Based upon water requirements for the 1000 ton/day Rocky Mountain Energy Co. mill total water requirements for a 1200 ton/day mill have been estimated to be 275 acre ft/yr ($0.25 \times 10^6$ gallons/day) for process make-up water and 26 acre ft/yr ($24 \times 10^3$ gallons/day) for domestic water. These water requirements totaling $0.28 \times 10^6$ gallons/day would come from local water wells.

### 5.5.2e Land Requirements

A typical uranium mill having a 1200 ton/day capacity would require about 300 acres of land.[1] This area would include the land occupied by the mill, tailings pond, access road, power lines, septic leach field, parking lots and ore storage piles. This land would be removed from other use for the lifetime of the mill, approximately 10 years.[2] Most of the land will be reclaimed after the mill is decommissioned and, with the possible exception of tailings piles, will be made available for other uses.[3]

### 5.5.2f Ancillary Energy

The energy requirements for a mill extracting uranium via the acid leach process have been estimated by Battelle Columbia Laboratories. They were for 9470 kwh per ton of $U_3O_8$ electrical energy and 210,500 cubic feet of natural gas per ton of $U_3O_8$.[1] A 1200 ton per day mill processing ore which contains 0.20 percent $U_3O_8$ and maintains a 93 percent recovery would produce 2.23 tons/day of $U_3O_8$. The energy requirments would then be about 880 kw of electrical energy and 19,600 cubic feet per hour of natural gas. Using a heating value of 1000 Btu/cubic feet[2] for the natural gas, the energy use represented by the gas would be $19.6 \times 10^6$ Btu/hr.

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[1] Nuclear Regulatory Commission. Operation of Bear Creek Project, Rocky Mountain Energy Company, Docket No. 40-8452. Washington, D.C.: Nuclear Regulatory Commission, Office of Nuclear Materials Safety and Safeguards, June 1977, p. 4-2.

[2] *Ibid.*

[3] *Ibid.*

### 5.5.3 Outputs

The outputs associated with a uranium milling plant are discussed in the following sections. The analyses were made for a plant size similar to a 1200 ton/day uranium ore processing facility. The outputs examined and quantified where possible include air emissions, water effluents, solid wastes, noise pollution, and occupational health and safety statistics.

### 5.5.3a Air Emissions

The radiological and non-radiological air emissions have been estimated for a 1000 ton/day mill.[3,4] Based on these data, the non-radiological air emissions for a 1200 ton/day mine are shown in Table 5-81. Table 5-82 lists the radiological air emissions and their sources for a 1200 ton/day mine.

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[1] Battelle Columbus Laboratories. Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing (Phase 5--Energy Data and Flowsheets, Intermediate-Priority Commodities). Columbus, Ohio: Battelle Columbus Laboratories, September 16, 1975, p. 207.

[2] *Ibid.*

[3] Nuclear Regulatory Commission. Operation of Bear Creek Project, Rocky Mountain Energy Company, Docket No. 40-8452. Washington, D.C.: Nuclear Regulatory Commission, Office of Nuclear Materials Safety and Safeguards, June 1977, p. 3-29, 3-34, 3-35, 3-37.

[4] Dames and Moore. Environmental Report, Bear Creek Project, Converse County, Wyoming, For Rocky Mountain Energy Company. Denver, Colorado, Rocky Mountain Energy Company, 1975, p. 3-14→3-22.

### 5.5.3b Water Effluents

Based upon data by the Nuclear Regulatory Commission on the Bear Creek Project, the liquid effluent from a 1200 ton/day uranium mill would be about 600 acre-ft year ($\sim 0.54 \times 10^6$ gallons/day) of a solution carrying mill tailings to a tailings pond.[1] This solution would be about 35% solids.[2] An organic residue will be retained in the tails as a film attached to the solid particles in the solution. The estimated releases to the tailings pond would be 8.2 lb/hr for kerosene, 0.26 lb/hr for amine, and 0.17 lb/hr for alcohol.

The estimated concentrations of radionuclides and chemicals present in the tailings solution are shown in Table 5-83. By design, all water going to the tailings ponds will be evaporated. The ponds will be lined and sealed to prevent seepage into the ground water system, and they will be sized and constructed to prevent overflow during heavy rains. Therefore there will be no direct wastewater effluents released to the environment.

### 5.5.3c Solid Wastes

The solid wastes generated by a uranium mill are mainly in the form of dust and mill waste tailings. The dust is

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[1] Nuclear Regulatory Commission. Operation of Bear Creek Project, Rocky Mountain Energy, Docket No. 40-8452. Washington, D.C.: Nuclear Regulatory Commission, Office of Nuclear Materials Safety and Safeguards, June 1977, p. 3-34

[2] *Ibid.* p. K-5.

## TABLE 5-81. ESTIMATED NON-RADIOLOGICAL AIR EMISSIONS FROM A 1200 TON/DAY URANIUM MILL

| Source | Gaseous Effluent | Quantity |
|---|---|---|
| Leaching process | $SO_2(g) + H_2SO_4(g)$ | 0.020 lb/hr |
| | Cl (g) | 0.022 lb/hr |
| Solvent extraction | Organic vapors (92% kerosene) | 0.030 lb/hr |
| Concentrate drying operation | Water vapor | 600 lb/hr |
| | Combustion products (mainly $CO_2$) | 120 lb/hr |
| | $SO_2$* | 1 lb/hr |
| | $NO_2$* | 0.30 lb/hr |
| Tailings pond | Water vapor | 55 to 150 x $10^3$ lb/hr |

*Only released if fuel-oil is used in place of natural gas

Source: Nuclear Regulatory Commission. Operation of Bear Creek Project, Rocky Mountain Energy Company, Docket No. 40-8452. Washington, D.C.: Nuclear Regulatory Commission, Office of Nuclear Materials Safety and Safeguards, June 1977, p. 3-29, 3-34 - 3-37.

Dames and Moore. Environmental Report, Bear Creek Project, Converse County, Wyoming, For Rocky Mountain Energy Company. Denver, Colorado, Rocky Mountain Energy Company, 1975, p. 3-14 - 3-22.

## TABLE 5-82. AVERAGE ANNUAL RADIOLOGICAL AIR EMISSIONS (IN CURIES) FROM A 1200 TON/DAY ACTIVE URANIUM MILL

| Source | Nuclide | | | | |
|---|---|---|---|---|---|
| | U-238 | Th-230 | Ra-226 | Rn-222 | Pb-210 |
| **Mine** | -- | -- | -- | 8.9 x $10^3$ | -- |
| **Ore pad & feeding** | 6 x $10^{-3}$ | 6 x $10^{-3}$ | 6 x $10^{-3}$ | 1.40 x $10^2$ | 6 x $10^{-3}$ |
| **Crushing & Grinding** | 3.4 x $10^{-2}$ | 3.4 x $10^{-2}$ | 3.4 x $10^{-2}$ | 3.4 x $10^{-2}$ | 3.4 x $10^{-2}$ |
| **Uranium concentrate** | 3.7 x $10^{-2}$ | 1.9 x $10^{-3}$ | 3.7 x $10^{-5}$ | -- | 3.7 x $10^{-5}$ |
| **Tailings** | -- | -- | -- | 1.9 x $10^3$ | -- |

Source: Nuclear Regulatory Commission. Operation of Bear Creek Project, Rocky Mountain Energy, Docket No. 40-8452. Washington, D.C.: Nuclear Regulatory Commission, Office of Nuclear Materials Safety and Safeguards, June 1977, p. 3-28.

TABLE 5-83. CONCENTRATIONS OF RADIONUCLIDES AND CHEMICALS IN TAILINGS SOLUTION[a]

| Radionuclide | Concentration, μCi/ml |
|---|---|
| U-238 | $2.4 \times 10^{-7}$ |
| U-234 | $2.4 \times 10^{-7}$ |
| Th-230 | $1.2 \times 10^{-4}$ |
| Ra-226 | $1.7 \times 10^{-7}$ |

| Chemical | Concentration, mg/ℓ |
|---|---|
| $SO_4$ | 700 |
| Fe | 1300 |
| Na | 280 |
| K | 63 |
| Mg | 320 |
| Ca | 570 |
| Al | 240 |
| As | 1.1 |
| Kerosene | 6.9 |
| Amines | 0.42 |
| Alcohol | 0.21 |

[a] Based upon measurements in a synthetic raffinate.

Source: Nuclear Regulatory Commission. Operation of Bear Creek Project, Rocky Mountain Energy Company, Docket No. 40-8452. Washington, D.C.: Nuclear Regulatory Commissions, Office of Nuclear Materials Safety and Safeguards, June 1977, p. 5-6.

produced from the ore piles and the yellowcake drying operation. An estimated 4 lb/acre/hr of dust would be generated by heavy equipment operating in the ore pile area.[1] Assuming an ore pile area of about 10 acres,[2] the dust introduced into the air from the ore pile would be 40 lb/hr. An estimated 0.04 lb/hr of dust would be emitted from the scrubber stack of the yellowcake drying system.[3]

The dust from the ore piles would contain radionuclides concentrations of the local ore. The dust from the scrubber would contain 98 percent of the uranium in the ore, 5 percent of the Th-230, and 0.2 percent of the Ra-226 and Pb-210 naturally occuring in the ore.[4]

The largest single effluent for the entire uranium milling operation is the production of barren tailings. This is the material left after the uranium has been leached from the lost ore. Approximately 1200 tons per day of sand, silt, and clay-sized particles would be generated at a 1200 ton per day mill.

The tailings are sent to a tailings pond where they are allowed to settle. When the barren tailings have filled the pond to capacity, the pond is removed from service, allowed to dry up, and reclaimed. Reclamation generally involves covering the pond with landfill, restoring its contour to that of the surrounding environment, fertilizing, and revegetating with local flora.

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[1] Nuclear Regulatory Commission. Operation of Bear Creek Project, Rocky Mountain Energy Company, Docket No. 40-8452. Washington, D.C.: Nuclear Regulatory Commission, Office of Nuclear Materials Safety and Safeguards, June 1977, p. 3-29.

[2] *Ibid.*, p. 3-38.

[3] *Ibid.*, p. 3-29.

[4] *Ibid.*, p. 3-35.

[5] Dames and Moore. Environmental Report, Bear Creek Project, Converse County, Wyoming, For Rocky Mountain Energy Company. Denver, Colorado: Rocky Mountain Energy Company, 1975, p. 3-20.

Prior to reclamation, wind erosion of the barren particles on the beaches of the tailings pond would be a source of fugitive dust. This effluent can be estimated from a wind erosion loss of 0.02 tons/acre/year[1] and a dry beach area of 30 acres.[2] The dust generated would then be approximately 3.3 lb/day.

### 5.5.3d Noise Pollution

The ore processing which takes place at a uranium mill will produce noise from the crushing and screening of the ore and from pumps used for material handling.[3] The noise from a crusher is expected to be 89 dBA at 30 feet and the noise from screening operation 96 dBA at 15 feet.[4] An equivalent noise level of 82 dB at 100 feet is estimated for the approximately 50 hermetically sealed pumps to be used in the mill.[5] Typically, the milling operation is entirely enclosed with a large building. This will attenuate the sound level by about 10 dB.[6] The equivalent noise level at a distance of 100 feet from the mill building would then be about 75 dB.[7]

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[1] Tennessee Valley Authority. Draft Environmental Statement, Martin Ranch Uranium Mining. Chattanooga, Tenn.: Tennessee Valley Authority, Div. of Environmental Planning, 1975, p. 4.6-4.

[2] Nuclear Regulatory Commission. Operation of Bear Creek Project, Rocky Mountain Energy Company, Docket No. 40-8452. Washington, D.C.: Nuclear Regulatory Commission, Office of Nuclear Materials Safety and Safeguards, June, 1977, p. 3-37.

[3] Dames and Moore. Environmental Report, Bear Creek Project, Converse County, Wyoming, For Rocky Mountain Energy Company. Denver, Colorado: Rocky Mountain Energy Company, 1975, p. 5-36.

[4] *Ibid.*

[5] *Ibid.*

[6] *Ibid.*

[7] *Ibid.*

### 5.5.3e Occupational Health and Safety

The results of a five-year survey on the occupational health hazards related to the operations of nuclear fuel cycle facilities indicate that a 1200 ton/day mill has the following occupational health statistics:[1]

| | |
|---|---|
| Deaths: | 0.046 per year |
| Injuries: | 14.1 per year |
| Man-Days Lost: | 873 per year |

### 5.5.4 Social Controls for Milling

This section will discuss federal and state regulations governing milling including those which control a) initial planning and land use, b) water quality, c) air quality, d) solid wastes, and 3) safety and product output.

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[1] U.S. Atomic Energy Commission. The Safety of Nuclear Power Reactors (Light Water-Cooled) and Related Facilities, Final Draft. WASH-1250, Springfield, Va.: NTIS, 1973.

### 5.5.5 Land Use and Planning

The majority of regulation in this area is at the federal level and some at the state as discussed below.

### 5.5.5a Land Use and Planning (Federal)[1]

The major method of control over fuel processing facilities is the licensing process. Three basic kinds of licenses apply to the various nuclear fuel cycle facilities and include: 1) licensing for the possession and use of source material, 2) licensing for the possession and use of special nuclear material, and 3) licensing for production and utilization facilities. The uranium mill is included only in item 1 above and items 2 and 3 are for enriched materials and use facilities respectively.

Any individual or company which possesses or uses source materials is required to obtain a license from the NRC.[2] An application for the license must be made to NRC at least nine months prior to beginning construction on the facility and must contain a description of the activity that will be performed as well as an EIS.[3] The permit is required to handle source material which is defined as uranium and/or thorium in any form which by weight makes up 0.05% of the ore.[4]

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[1] This procedure applies to "non-agreement" states and see Section 5.5.5b for discussion of difference.

[2] Atomic Energy Act of 1954. § 2014 and 10 C.F.R. 20.

[3] 10 C.F.R. § 40.31(f).

[4] 10 C.F.R. § 40.4(h).

NRC has listed the requirements imposed on a source material license (in this case a mill) which must be met before a license is granted.[1] These requirements include: 1) an authorized purpose for the process, 2) a qualified applicant, 3) use of adequate equipment, facilities, and procedures, 4) it is the best interests of the public, and 5) that NEPA compliance exists. The above requirements have resulted in two specific review processes by NRC: a safety assessment and an environmental assessment.[2]

The safety review is, as its title suggests a careful analysis to be sure that the mill will be as safe as possible. Factors that are considered include such things as worker safety (radiation), security plans, procedures used, and workers qualifications and training programs.

The environmental assessment is an effort to comply with the various aspects of NEPA. Under an NRC issued regulation, an EIS must be prepared prior to issuing "a license to process and use source material for uranium milling.[3] Although, as noted earlier the application must be submitted nine months ahead of planned construction; there is also a requirement that the EIS be completed prior to construction.[1] Although the EIS is the primary tool of the environmental assessment other factors are considered.

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[1] See 10 C.F.R. § 40.32.

[2] Shaw, Permits Required to Open a Uranium Mill, RMMLI Uranium Conference 1976, p. 12-5.

[3] 10 C.F.R. § 51.5(5).

Following the completion of both review processes, NRC may require revisions in applicant's proposal or it may attach conditions to the permit. Normally, such items as monitoring programs, safety programs, and quality assurance programs become conditions attached to the permit.[2] Also NRC requires some type of financial assurance of performance. This can be the surety bond executed by the developer to a state or federal agency to insure reclamation of disturbed lands and stabilization of tailings. Often this bond is tied to the mining reclamation bond, normally required by the state.[3]

Two additional bonds are usually required, one to insure that post-reclamation and stabilization monitoring are carried out and the other to insure that annual maintenance of tailings dams, tailings piles, and diversion structure is performed. To insure that the tailings disposal area is not used for other development, NRC requires a 50 year restrictive covenant on the land title to run from the date of termination of the license.[4]

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[1] 10 C.F.R. § 40.32(e).

[2] Shaw, RMMLI, p. 12-7.

[3] Ibid.

[4] It appears this is an effort to get at a lack of regulatory authority for either EPA or NRC over tailings piles after the license has expired. Recently the House Interior Committee's Subcommittee on Energy and the Environment held hearings wherein testimony revealed that EPA felt it lacked authority and an ERDA representative claimed EPA and NRC had authority. A subcommittee member's conclusion was that no one wants to take credit for mill tailings so that perhaps additional legislation is necessary. Nucleonics Week, Vol. 18, No. 21, May 26, 1977, p. 2.

The monitoring bond and annual work bond are usually held by the NRC since most states (those called "non-agreement") do not have agencies able and willing to perform such supervision.

### 5.5.5.b State Siting Laws

As noted in Chapter 2 siting regulation can be direct or indirect. Examples of indirect siting laws include such controls as those over air pollution or solid waste disposal. The discussion that follows will be devoted only to direct siting regulation, where those indirectly affecting siting will be discussed in other sections.

The primary permit described in Section 5.5.5.a, the source material license, can in some cases be issued by a state. The term used to describe such states is "agreement states" and its meaning is literal in that in fact by agreement between NRC and the state, the state is authorized to issue the permit. In the eight state study area the breakdown is as follows:[1]

| Agreement States | Non-Agreement States |
|---|---|
| Colorado | Utah |
| New Mexico | Wyoming |
| North Dakota | Montana |
| Arizona | South Dakota |

In the agreement states, the state program for the issuance of source material permits has been reviewed by the NRC and deemed to be as "good" as the NRC's.[2] Pursuant to statute NRC has delegated some of its responsibilities to those states.[3]

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[1] Shaw, p. 12-1 and 37 F. Reg. 22162, Oct. 18, 1972.

[2] Ibid.

[3] The procedure for the state issued permit appears to be similar to that of NRC's which is what one would expect from the circumstances. The state procedure will not, therefore, be described here.

In addition to the indirect siting controls at state level discussed in the introduction to this section, other state laws may be brough into action. For example, many states require prior approval of the mining plan and usually those mining plans require some discussion of the tailings (even from a mill) associated with the mining plan.

### 5.5.6 Water Quality

Generally within the water quality area, permits can be required at federal and state levels of government depending upon the effluent discharge. For a general understanding of this subject, Chapter 2 should be read to get an overall picture. Below will be recorded the laws and regulations at both levels of government and it is important to note that water quality can be controlled from various directions (e.g., drinking water quality or federal and state standards for streams and lakes or effluents standards).

### 5.5.6.a Federal Water Quality Statutes and Regulations

At the federal level, statutes affecting uranium mills and which are related to water quality are found in the planning activities noted in Section 5.5.5, the FWPCA of 1972 and the Safe Drinking Water Act of 1974. Additionally Section of Chapter 2 contains the permit required under FWPCA from the Corps of Engineers.

The procedure for obtaining a discharge permit for a uranium mill is the same as any other discharge permit and is described in Chapter 2. Presently, a mill which does not discharge effluents into "waters of the U.S." will not require a permit from EPA. EPA is considering publishing regulations which define "best practicable treatment" standards for uranium mills,[1] which will then offer to the mill a specified option to the no-discharge holding pond.[2]

Under the terms of the Safe Drinking Water Act, it is possible to arrive at an interpretation which will require consideration of drinking water sources (underground and surface) when locating a facility which would likely include uranium mills.

### 5.5.6.b State Regulation

As described in Chapter 2, the control of water quality, although authorized by federal law has been delegated to some of the states. In certain technologies connected with a uranium mill other state laws come into play and they will be described below.

Many states require approval of all waste water treatment systems including those for tailings pond, sewage lagoon, or septic tank.[3] Additionally many states regulate milling activities under state mining regulations. Hence that state agency and permitting process will address milling and tailing disposal.[4] How much indirect control of mill procedures exists within these state laws will vary at each state. Also because most uranium mills are located in the arid West, the local State Engineers will usually be required to give approval of the tailings dam or other impoundment.[5]

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[1] RMMLI Uranium Conf. Shaw, p. 12-3.

[2] See discussion in Section 2.9.

[3] op.cit.

[4] Ibid., p. 12-3 and 12-9.

[5] Ibid.

### 5.5.7 Air Quality

Air quality for uranium mills is regulated no differently than that for other facilities.

As noted in Section 5.5.3.a, the major criteria pollutant emitted from a uranium mill is in the form of an $NO_x$ emission and the federal ambient standard is set up in Section 2.8. The ambient standard is relevant when questions of new source review or set-off policies are considered.[1] No NSPS have been set up for the uranium mills. But EPA is considering using the Toxic Substance Control Act of 1976 to control wastes from an uranium mill.[2]

### 5.5.8 Solid Wastes

Regulation of solid waste disposal from a uranium mill generally reflects two concerns for the tailings, one radioactivity, the other mining-reclamation. Non-agreement states usually regulate the latter, while agreement states can regulate both areas. Of course NRC takes on radioactivity regulation in non-agreement states. The general procedures of both will be described below.

### 5.5.8.a Solid Wastes Federal

As described in Section 5.5.a, the main concerns in the solid waste area from a regulatory viewpoint are the tailings stabilization and monitoring. Presently NRC appears to require that licensee impose "restrictive covenants on the land where tailings are stored for at least fifty (50) years after termination of a license."[1] One covenant and a respective surety bond to guarantee performance, requires that at least annual surveys of the site both environmental and radioactive be made. Additionally the tailings piles and dams must be maintained and a bond filed insuring performance. The requirements listed above can be supervised by NRC or a designated agency in an agreement state.

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[1] Again see Section 2.8 for discussion of each.

[2] Note also that specific nuclear material (e.g., "source material as defined by the Atomic Energy Act of 1954) is exempted from the Toxic Substances Control Act of 1976, Section 3(2) (A) (iv).

### 5.5.8b State Regulation of Uranium Tailings

In both agreement and non-agreement states, state mining laws were written to include either specifically or indirectly the regulation of mills and tailings disposal. The main concern of the state in this context is tailings disposal and more importantly the reclamation of the land and "returning the surface to a land use consistent with its pre-disturbance use."[2]

### 5.5.9 Safety and Product Output (Radiation)

Safety regulation at the uranium mill and product regulation are tied together in the regulation of radiation. The federal OSHA standards for ionizing radiation and worker safety are equivalent to the standards required by NRC in agreement states.[3] In summary those regulations set cumulative limits for exposure.

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[1] Shaw, RMMLF, p. 12-8.

[2] *Ibid.*

[3] 37 F. Reg. 22162, Oct. 18, 1972.

TABLE 5-84.

| | Rems per Calendar Quarter[1] |
|---|---|
| Whole body | 1¼ |
| Hands and/or feet | 18¾ |
| Skin | 7½ |

In the above table one "rem" is defined as the equivalent biological effect of one roentgen of x-rays.[2]

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[1] 37 F. Reg. 22158, Oct. 18, 1972.

[2] 29 C.F.R. § 1910.96 (a) (7) 1973.

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